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SPACING IN RELATION TO THE DEVELOPMENT OF THE FLAX PLANT[1]

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Rate-of-spacing tests have been conducted without much attention to the development of the individual plants on plats sown at different rates. The effectiveness of the various rates of seedings employed has been measured by the most important economical consideration, namely, yield. There is no doubt as to the advisability of using this criterion of performance [illegible]n. It is possible, however, to throw additi[illegible]t by considering in detail the response shown [illegible]With this in mind it was deemed worth while [illegible]riment to find how differences in the amount [illegible]he development of separate plants may influence the physical and chemical make-up of the flax plant.

PLAN OF THE EXPERIMENT

Flax was seeded with a disk drill at the rate of 35 pounds per acre in 1929 and 45 pounds in 1930. The increase in the rate of seeding employed in the second year of the experiment was due to the fact that the large-seeded variety Bison was used in that season, whereas the smaller-seeded North Dakota Resistant No. 114 variety was used in the first year of the test. The dates of seeding for the two respective seasons were June 10 and April 15.

The area used for the experiment was laid off into plats 5 feet long and 9 drill rows wide in 1929 and 6 feet long by 8 drill rows in width in 1930. The drill rows were 6 inches apart. All plats were replicated three times in 1929 and four times in 1930. The drill rows

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bordering the outside of the plats were cut out at the time the plats were established. To obviate border effects the two drill rows on either side of the plats were discarded at harvest time. This left the plats seven and six drill rows wide for the two respective seasons. All determinations, with the exception of the oils, were made separately on the individual rows, but the results are reported on the basis of average values for the entire plat concerned.

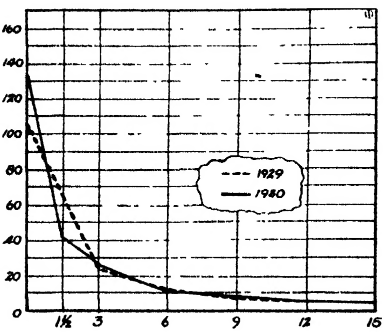

FIG. 1.—Number of plants per drill row for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930

A few days after the plants emerged they were thinned down to the desired distances in the drill rows. One series of plats was left unthinned and averaged (Table 1) 21.34 and 22.33 plants per foot of drill row for the two seasons of the test. Plants in the other plats were thinned down to approximate distances of 3, 6, 9, and 12 inches in 1929, and 1½, 3, 6, 9, 12, and 15 inches in the rows in 1930. This gave a wide range of spacings. The actual numbers of plants per foot of drill row for each of the respective approximate spacings are given in Table 1.

RESULTS

NUMBER OF PLANTS PER FOOT OF DRILL ROW

The number of plants per row as well as the number per foot of drill row are given in Table 1, and are shown graphically in Fig. 1. The decrease in number of plants per row from the unthinned to the subsequent spacings was very rapid. The differences in the number of plants per row in the more distant spacings were but small. Due to this, the greatest differences in the development of plants will be found in comparisons of plants grown on the unthinned plats and on those of the more immediate spacings. The introduction of the 1½-inch spacing in 1930 made for more symmetrical curves and reduced somewhat the great difference in the number of plants per row from the unthinned lot to that of the first definitely spaced plat.

HEIGHT OF PLANTS

Very close spacings, as in the unthinned plats, served to reduce the height of the plants materially. It is interesting to note, however, as

TABLE 1.—*Characteristics of flax plants grown on plats with different spacings between plants.*

Approximate spacings, inches	No. of plants per drill row*	No. of plants per foot of drill row	Height of plants, cm	No. of stems per plant	No. of secondary branches per plant	No. of bolls per plant	No. of seeds per boll
				1929 Results			
Unthinned	106.7	21.34	56.3	1.20	——	9.39	5.88
3	24.6	4.92	63.4	3.44	——	28.67	6.07
6	12.9	2.58	64.2	4.24	——	37.39	6.81
9	8.0	1.60	65.4	4.59	——	50.91	6.69
12	6.7	1.34	63.2	4.78	——	63.36	6.25
				1930 Results			
Unthinned	134.0±3.14	22.33±.52	57.1±.59	[illegible].09±.03	4.68± .15	8.40± .30	7.26
1½	41.5± .97	6.92±.16	64.5±.55	2.40±.07	11.82± .38	23.43± .84	8.04
3	25.0± .59	4.24±.10	65.1±.56	3.31±.09	15.87± .52	32.01±1.14	8.04
6	12.3± .29	2.05±.05	64[illegible]	[illegible].61±.13	23.86± .78	51.10±1.82	7.92
9	8.5± .20	1.42±.03	64[illegible]	[illegible].99±.14	29.95± .85	67.29±2.40	7.31
12	6.7± .16	1.12±.03	64[illegible]	[illegible].05±.14	24.68± .81	68.85±2.46	7.69
15	5.7± .13	0.95±.02	64[illegible]	[illegible].55±.16	30.96±1.02	74.22±2.65	7.79

Approximate spacings, in inches	Weight of seed per boll, grams	Total weight of plants per drill row, grams	Weig[illegible] per [illegible] g[illegible]	[illegible]Weight [illegible]er plant, grams	Weight of seed per plant, grams	Weight of 1,000 seeds, grams	Oil in seed %
				[illegible]lts			
Unthinned	0.0230	96.20	22.[illegible]	[illegible].92	0.21	3.80	33.57
3	0.0240	68.57	16.[illegible]	[illegible].83	0.68	3.85	34.22
6	0.0263	57.22	12.7	4.49	0.97	3.81	35.13
9	0.0255	48.57	11.1	5.73	1.28	3.76	36.36
12	0.0237	45.18	9.9	6.71	1.48	3.74	36.36
				1930 Results			
Unthinned	0.0364±.0007	161.4±5.24	38.6±1.41	1.25±.05	0.30±.01	4.92±.05	36.75
1½	0.0376±.0007	129.6±4.21	36.2±1.32	3.13±.12	0.88±.04	4.67±.05	36.75
3	0.0388±.0007	119.7±3.89	31.0±1.13	4.79±.18	1.24±.05	4.82±.05	36.19
6	0.0379±.0007	87.6±2.91	23.5± .86	7.29±.27	1.91±.08	4.72±.05	36.87
9	0.0356±.0007	78.0±2.54	20.3± .74	9.20±.34	2.40±.10	4.88±.05	36.84
12	0.0369±.0007	65.2±2.12	17.1± .62	9.74±.36	2.54±.10	4.80±.05	36.87
15	0.0368±.0007	58.6±1.90	15.5± .57	10.76±.40	2.74±.11	4.74±.05	35.55

*The drill rows were 5 feet long in 1929, and 6 feet in 1930.

may be seen from Table 1 and Fig. 2, that there were practically no differences in the average heights of plants from the 1½- to the 15-inch spacings.

Correlation studies with three different sets of data are reported in Table 2. The results reported were taken from the averages of all plats grown in 1929, from the separate plats of each spacing grown in 1930, and from the separate rows of the unthinned plats grown in the latter season. These respective sets of correlation data will, for the sake of brevity, be referred to as originating from the 1929 and 1930 plats and the 1930 unthinned plats.

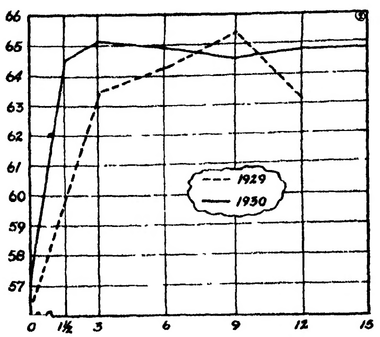

FIG. 2—Height of plants in centimeters for each of the approximate spacings, from the unthinned (o) to the 12- and 15-inch spacings of flax in 1929 and 1930

It will be seen from Table 2 that negative correlations were obtained in all instances where height of plants was correlated with density of stand. The values of r were —.972 ± .017, — .820 ± .042, and — .138 ± .019 for the 1929 and 1930 plats and the 1930 unthinned plats,. respectively. The first two values given are very significant. In the case of the 1930 unthinned plats the differences in the height and spacings in the rows were not great enough to yield definite and significant correlations.

Correlation studies between height of plants and number of stems per plant show values of .934 ± .038, .710 ± .063, and .197 ± .132 for the three respective series of plats. In the unthinned plats, having the shortest plants, the number of stems per plant was but slightly greater than one. In the spaced plats the number of stems per plant increased with increase in distance between plants, while the height of the plants remained more or less constant.

Due to the small number of stems per plant on the unthinned plats, the number of bolls per plant was small, consequently correlation studies between height of plants and number of bolls per plant gave much the same results as between height and number of stems per plant. The values of r for the respective series of plats were .754 ± .130, .614 ± .080, and .110 ± .136.

The weight per plant increased in all cases with increase in height for the respective plats as indicated by the values .781 ± .117, .624 ± .078, and .439 ± .111. Seed production per plant and height

TABLE 2.—*Correlation coefficients for various combinations of characteristics studied in flax spacing tests in 1929 and 1930.*

	Height of plants	No. of stems per plant	No. of secondary branches per plant	No. of bolls per plant	Total weight of plants per drill row	Weight of seed per drill row	Total weight of individual plants	Weight of seed per plant	Weight of seed per boll	Weight of 1,000 seeds
All 1929 Plats										
No. of plants per drill row	-.972±.017	-.982±.011	—	-.855±.081	.958±.024	.940±.035	-.754±.130	-.881±.067	.000±.000	.252±.283
Height of plants	—	.934±.038	—	.754±.130	-.902±.056	-.875±.071	.781±.117	.707±.110	.000±.000	.151±.295
No. of stems per plant	—	—	—	.928±.042	-.904±.003	-.994±.003	.945±.032	.051±.029	.000±.000	-.423±.248
No. of bolls per plant	—	—	—	—	-.960±.024	-.965±.021	.992±.005	.996±.004	.000±.000	-.682±.161
Total weight of plants per drill row	—	—	—	—	—	.997±.002	-.973±.016	-.979±.013	.000±.000	.512±.225
Weight of seed per drill row	—	—	—	—	—	—	-.983±.010	-.912±.050	.000±.000	.550±.210
Total weight of individual plants	—	—	—	—	—	—	—	.999±.001	.000±.000	-.681±.162
Weight of seed per plant	—	—	—	—	—	—	—	—	.000±.000	-.663±.199
Weight of seed per boll	—	—	—	—	—	—	—	—	—	.000±.000
All 1930 Plats										
No. of plants per drill row	-.820±.042	-.863±.032	-.835±.038	-.805±.045	.831±.035	.720±.060	-.797±.047	-.814±.043	.061±.127	.530±.092
Height of plants	—	.710±.063	.675±.069	.614±.080	-.486±.097	-.473±.089	.624±.078	.625±.078	.394±.108	-.647±.074
No. of stems per plant	—	—	.989±.003	.969±.008	-.896±.025	-.870±.031	.970±.007	.971±.007	.013±.127	-.054±.127
No. of secondary branches per plant	—	—	—	.968±.008	-.878±.020	-.858±.034	.966±.009	.969±.008	-.022±.127	-.061±.127
No. of bolls per plant	—	—	—	—	-.909±.022	-.883±.028	.990±.003	.995±.001	-.075±.127	-.037±.127
Total weight of plants per drill row	—	—	—	—	—	.927±.018	-.895±.026	-.908±.022	.101±.126	.059±.127
Weight of seed per drill row	—	—	—	—	—	—	-.881±.028	-.869±.031	.334±.113	.010±.127
Total weight of individual plants	—	—	—	—	—	—	—	.993±.002	.043±.127	-.004±.127
Weight of seed per plant	—	—	—	—	—	—	—	—	.003±.127	-.041±.127
Weight of seed per boll	—	—	—	—	—	—	—	—	—	-.015±.127
Drill Rows of 1930 Unthinned Plats										
No. of plants per drill row	-.138±.019	-.579±.091	-.634±.082	-.647±.080	.409±.115	.012±.138	-.766±.057	-.859±.119	-.366±.119	—
Height of plants	—	.197±.132	.613±.086	.110±.136	.501±.103	-.583±.091	.439±.111	-.080±.137	-.251±.129	—
No. of stems per plant	—	—	.705±.069	.709±.069	.199±.132	.052±.173	.772±.056	.574±.092	-.009±.138	—
No. of secondary branches per plant	—	—	—	.542±.097	.224±.131	-.267±.128	.823±.059	.508±.102	.000±.000	—
No. of bolls per plant	—	—	—	—	.032±.138	.284±.127	.704±.069	.742±.062	-.284±.127	—
Total weight of plants per drill row	—	—	—	—	—	-.148±.135	.237±.130	-.328±.123	-.561±.094	—
Weight of seed per drill row	—	—	—	—	—	—	-.148±.135	.414±.114	.203±.132	—
Total weight of individual plants	—	—	—	—	—	—	—	.700±.070	.002±.138	—
Weight of seed per plant	—	—	—	—	—	—	—	—	.402±.116	—

showed positive correlations for the 1929 and 1930 plats, namely, to the extent of .797 ± .110 and .625 ± .078, but showed no association in the 1930 unthinned plats.

The total weight of plants per row, as also the production of seed per row, decreased from the denser to the more distant spacings. This resulted in negative correlations between height of plants and these two factors, except in the case of height of plants and weight of plants per row in the 1930 unthinned plats where a positive correlation of .504 ± .103 is in evidence. Correlation studies between height of plants and weight of seed per row showed values of — .875 ± .071, — .473 ± .089, and — .583 ± .091. Correlations between height of plants and weight of plants per row show values of — .902 ± .056, — .486 ± .097, and — .504 ± .103. These figures indicated that while the weight of plants per row in the case of the 1930 unthinned plats increased to some extent with an increase in the height of plants, this increase did not result in greater seed production. High degrees of correlation between density of stand and seed production per row are in evidense for the 1929 and also the 1930 plats, but especially for the season of 1929 when moisture was abundant. These two factors show no correlation in the 1930 unthinned plats, thus indicating that an increase in the density of the stand would not have led to increased seed production. The plants were as closely spaced as could be supported under the climatic conditions of that season.

The taller plants showed in both correlation series calculated in 1930 a greater number of secondary branches than shorter growing plants, the values of r were .675 ± .069 and .613 ± .086 for the 1930 and 1930 unthinned plats, respectively. No relationships are in evidence between height of plants and weight of seed per boll and weight of 1,000 seeds.

NUMBER OF STEMS PER PLANT

An uninterrupted increase in the number of stems per plant was found in going from the denser to the thinner stands (Fig. 3). The increase in the number of stems per plant was greatest from the unthinned to the 1½- and 3-inch spacings. This was to be expected in view of the rapidly decreasing number of plants per foot of drill row, namely, 21.3, 5.9, 2.6, 1.6, and 1.3, in going from the unthinned to the 3-, 6-, 9-, and 12-inch spacings in 1929 and 22.3, 6.9, 4.2, 2.1, 1.4, 1.1, and 0.9 for the so-called unthinned, 1½,- 3-, 6-, 9-, 12-, and 15-inch spacings in 1930, respectively.

Negative correlations of — .982 ± .011, — .863 ± .032, and — .579 ± .091 were found in the 1929 and 1930 plats and 1930 unthinned plats, respectively, between the number of stems per plant and number of plants per drill row. Other negative correlations were found between the number of stems per plant and the total weight of plants per row and the weight of seed per row, the values of r for the former being — .994 ± .003 and — .896 ± .025 and for the latter — .994 ± .003 and — .870 ± .031 for the 1929 and 1930 plats, respectively. This showed that the increase in the number of stems per plant in the more distant spacings was not great enough to compensate for the decrease in the number of plants per row. No significant correlations between number of stems per plant and weight of plants per row and seed production per row were found in the 1930 unthinned plats. Nearly all the plants in these plats, as has been pointed out, had but one stem, no significant correlations could therefore be expected.

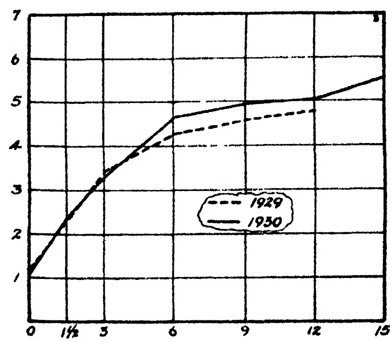

FIG 3—Number of stems per plant for each of the approximate spacings, from the unthinned (o) to the 12- and 15-inch spacings of the flax in 1929 and 1930.

Positive correlations were in evidence in all series of plats between number of stems per plant and number of bolls per plant, the values of r being .928 ± .042, .969 ± .008, and .709 ± .069; between number of stems per plant and weight per plant to the extent of .945 ± .032, .970 ± .007, and .772 ± .056; also between number of stems per plant and weight of seed per plant to the extent of .951 ± .029, .971 ± .007, and .574 ± .092. The number of stems per plant and number of bolls per plant showed correlations of .989 ± .003 and .705 ± .069 for the 1930 and 1930 unthinned plats, respectively.

NUMBER OF SECONDARY BRANCHES

The number of secondary branches per plant were counted for the 1930 crop only. The greatest increase in the number of these branches was found from the unthinned to the more immediate spacings. As may be noted from Fig. 4, no very great increases in the number of secondary branches were found beyond the 6-inch spacing.

Negative correlations to the extent of — .835 ± .038 and — .634 ± .082 were found between the number of secondary branches per

plant and the number of plants per row for the 1930 and the 1930 unthinned plats.

A negative correlation of -- .878 ± .029 was in evidence for the number of secondary branches per plant and the total weight of plants per row in the 1930 plats. These two factors showed no significant correlations for the 1930 unthinned plats

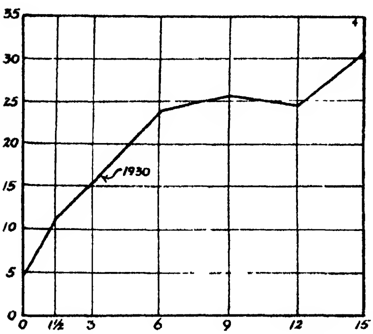

FIG. 4—Number of secondary branches per plant for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1930.

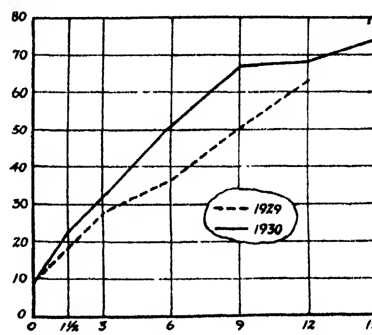

FIG. 5.—Number of bolls per plant for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930

High positive correlations were found in the 1930 plats between the number of secondary branches per plant and the number of bolls per plant, weight per plant and weight of seed per plant, the values of r being .968 ± .008, .966 ± .009, and .969 ± .008, respectively. The values for the 1930 unthinned plats were not as great, but were significant nevertheless, the highest value, namely, .823 ± .059, being found in the case of number of secondary branches per plant and weight per plant.

NUMBER OF BOLLS PER PLANT

The number of bolls per plant, as may be seen from Fig. 5, increased at a rather consistent rate with increase in space available to the plants. The rate of increase of the number of bolls per plant was greater after the 6-inch spacing than that of the number of secondary branches. This indicated that the secondary branches continued to branch out at the more distant spacings, while the increase in the number of these branches was rather small beyond the 6-inch spacing.

Decided negative relationships were found between number of bolls per plant and number of plants per row, the values for the respective series being — .855 ± .081, — .805 ± .045, and — .647 ± .080. Negative correlations were found also between number of

bolls per plant and weight of plants and yield of seed per row, the values of r being — .960 ± .024, — .909 ± .022, — .965 ± .021, and — .883 ± .028 for the 1929 and 1930 plats, respectively. No correlations between these factors were found in the case of the 1930 unthinned plats.

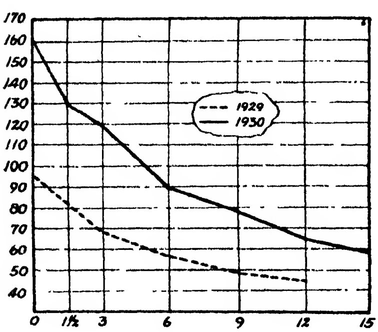

Fig. 6.—Total weight of plants per row in grams for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930

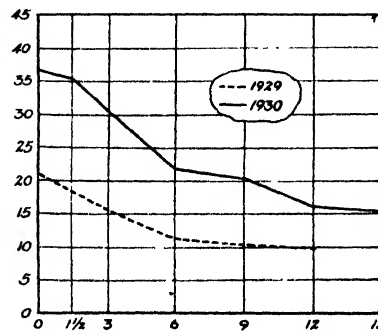

Fig. 7.—Weight of seed produced per row, in grams, for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930

Very high positive correlations were found between the number of bolls per plant and weight per plant and weight of seed per plant, the values of r for these two factors being .992 ± .005, .990 ± .003, and .704 ± .069 for the former and .996 ± .004, .995 ± .001, and .742 ± .062 for the latter in the 1929 and 1930 plats and the 1930 unthinned plats, respectively.

The relationship between number of bolls per plant and yield per plant is sufficiently close to be of value for prediction purposes. The actual field performance of flax, however, is not determined so much by the yield of seed per plant as by the yield of seed per unit of area. This is evident from a study of yields of the different spacing plats (Figs. 6 and 7).

WEIGHT OF PLANTS PER ROW

The weight of plants per row decreased in much the same proportion as the number of plants per row, as is evident from the rather high degrees of correlation of .958 ± .024, .831 ± .035, and .409 ± .115 between these two characters for the three series of plats. As may be seen from Fig. 6 and from the high coefficient of correlation, the weight of plants per row in 1929 decreased about as rapidly as the number of plants per row. The weight of the plants in the 1930 plat did not decrease as rapidly as the number of plants per row.

The greater development of the plants in the more distant spacings compensated to a degree for the decrease in the number of plants. This was true to even a greater extent in the 1930 unthinned plats as is evident from the comparatively low value of r.

A very close relationship was found between the weight of plants and the weight of seed per row, the values of r being .997 ± .002 and

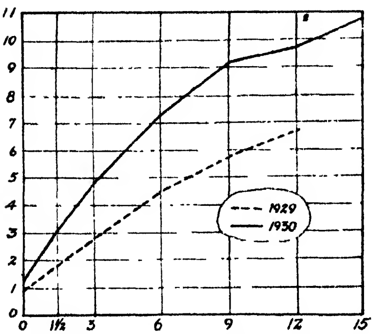

FIG. 8.—Weight of individual plants in grams for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930.

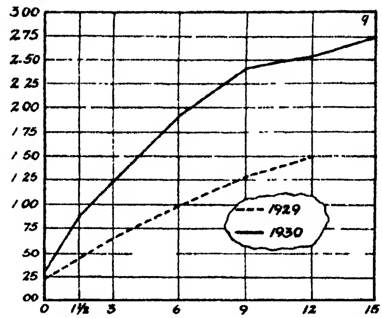

FIG. 9.—Yield of seed per plant in grams for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930

.927 ± .018 for the 1929 and 1930 plats, respectively. These two factors showed no correlation in the 1930 unthinned plats. This indicated that a still greater increase in the weight and number of plants per row would not have yielded a greater amount of seed in the unthinned plats.

Definite negative correlations were found between the weight of plants per row and the weight per plant and weight of seed per plant. The values of r for the first two factors were — .973 ± .016 and — .895 ± .023, while correlations between the weights of plants per row and weight of seed per plant gave values of — .979 ± .013 and — .908 ± .022 for the 1929 and 1930 plats, respectively.

WEIGHT OF SEED PER ROW

The weight of seed per row decreased at the same rate as the weight of plants per row from the dense to the more distant spacings. This was to be expected in view of the high degrees of correlation between these two factors. Correlations between weight of seed and number of plants per row gave values of .940 ± .035 and .729 ± .060 for the 1929 and 1930 plats. There was somewhat of a tendency for the seed yields to hold up at the closer spacings in 1930, or at least not to decrease as rapidly as the number of plants per row.

As in the case of weight of plants per row, decided negative correlations were in evidence between the weight of seed produced per row and weight per plant and weight of seed per plant. The values of these correlations were — .983 ± .010 and — .881 ± .028 for the former and — .912 ± .050 and — .869 ± .031 for the latter for the two respective seasons of the test.

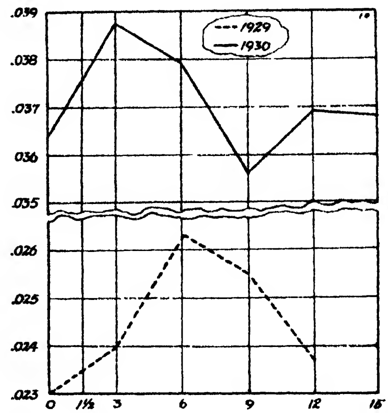

FIG. 10.—Weight of seed per boll, in grams, for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930.

WEIGHT OF PLANT

As was to be expected, the weight per plant increased rapidly with increase in space for development. Negative correlations to the extent of — .754 ± .130, — .797 ± .047, and — .766 ± .057 were found in correlations of weight per plant and number of plants per row. Close positive correlations to the extent of .999 ± .001, .993 ± .002, and .700± .070 were found between weight per plant and weight of seed per plant in the 1929 and 1930 plats and the 1930 unthinned plats, respectively. Even though the weight per plant and the weight of seed per plant increased greatly with increase in space available to individual plants in the more distant spacings, the increase was not sufficiently great to compensate for the decrease in the number of plants per row. As a result, the yields on the more distant spacings, as may be seen from Fig. 7, were appreciably lower than those on the unthinned plats and on the closer spacings.

YIELD OF SEED PER PLANT

The curves showing weight per plant (Fig. 8) and weight of seed per plant (Fig. 9) at the respective spacings are almost identical. This is evident also by the high degrees of correlation between these factors. Negative correlations to the extent of — .881 ± .067, — .814 ± .043, and — .859 ± .036 were found between yield of seed per plant and number of plants per row.

WEIGHT OF SEED PER BOLL

As may be seen from Fig. 10, no relationships were found between weight of seed per boll and the amount of space available for the development of flax plants. The weight of seed per boll remained

remarkably constant for the different spacings. Likewise, the number of seeds per boll, as shown in Table 1, fluctuated in but narrow limits for the different spacing plats. Correlations between weight of seed per boll and number of plants per row gave values of .000 ± .000, .061 ± .127, and — .366 ± .119 for the 1929 and 1930 plats and 1930 unthinned plats, respectively.

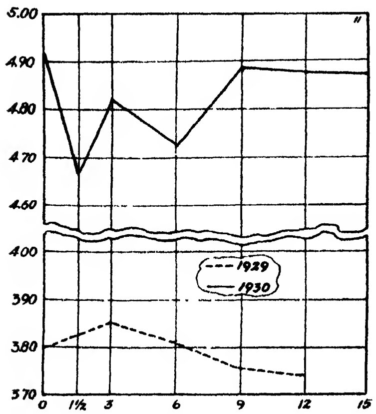

FIG. 11 — Weight of 1,000 seeds, in grams, for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930.

The seed yield of flax is highly dependent on the number of bolls produced per plant or more definitely per unit of area. That seed yields per plant are determined to a great extent by the number of bolls produced is brought out by the high correlations between number of bolls per plant and weight of seed per plant. These values for the three respective series of plats used made .996 ± .004, .995 ± .001, and .742 ± .062. Environmental factors, at least as affected by changes in amount of space available for the development of individual plants, seem to have had very little influence on the amount of seed produced per boll in the two seasons of the test. No significant correlations were found between weight of seed per boll and any of the plant characteristics studied in the course of this investigation.

WEIGHT OF 1,000 SEEDS

As may be seen from Fig. 11, there was no relationship between the amount of space available to the flax plant and the size of seed produced as measured by the weight of 1,000 seeds. Likewise, this factor, as was also the case with the weight of seed produced per boll, showed no correlations of significance with any of the plant characteristics considered in this study.

No differences in the quality of the seed produced on the various spacing plats, such as differences in weight per bushel, plumpness, and general appearance, could be detected. The greater the amount of space available to the plant, the greater was the number of bolls and consequently the number of seeds produced per plant. The size of the seed remained fairly constant, however.

The great difference in the weight of the seed in the two years of the investigation was due to the fact that two different varieties, viz., North Dakota Resistant No. 114 and Bison, the former a small-seeded and the latter a large-seeded type, were used in 1929 and 1930, respectively.

OIL CONTENT OF SEED

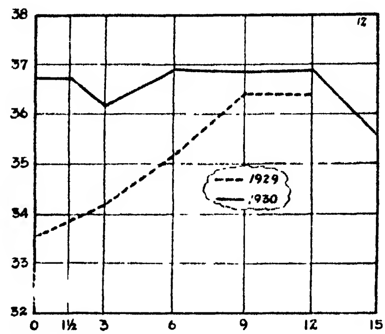

FIG. 12.—Oil content of seed, in per cent, for each of the approximate spacings, from the unthinned (0) to the 12- and 15-inch spacings of flax in 1929 and 1930.

As may be seen from Table 1 and Fig. 12, the percentage of oil in the seed showed in the season of 1929 a slight tendency to increase from the close to the more distant spacings. This was not substantiated by the 1930 results, when the oil content of seed produced on the different spacing plats remained unchanged. In the season of 1929, when moisture during the flowering and ripening periods was abundant, it required from 2 to 8 days more for plants on the more distant spacings to reach maturity than was required by those on the unthinned plats. It was hot and dry during the flowering and ripening period in 1930, and this reduced the intervals between the dates of maturity between the various plats to from 1 to 5 days. These seasonal differences may account in part for the differences in the trends in the oil content of the seed for the two seasons of the test. At any rate the differences in the oil contents of the seeds from the different plats are not great enough to be of practical significance insofar as the differences in spacings here employed are far greater than would result from slight differences in rates of seedings commonly used. While the temperature of the ripening period of the season of 1930 was extremely high and served to bring about early maturity, there was, nevertheless, a sufficient supply of moisture in the soil of all plats to assure a fairly normal development of the seed.

DISCUSSION

It will be well to consider the high yields of the unthinned and closely spaced plats in comparison with the much lower seed yields of the more distant spacings. The differences in these yields are rather outstanding. As was to be expected, the weight of plants per row dropped off somewhat more rapidly than the seed yields. Yet, by

the time the 3-inch spacings were reached, the seed yields were considerably below those of the unthinned plats.

Since the weight and number of seeds per boll remained more or less constant at the different spacings, the seed yields depended primarily on the number of bolls that could be produced per unit of area. The high degrees of correlation found between number of bolls per plant and yield of seed served to substantiate this fact. Correlation studies between number of bolls per plant and yield of seed per plant gave values of $r = .996 \pm .004$ in the 1929 plats, $r = .995 \pm .10a$ in the 1930 plats, and $r = .742 \pm .062$ in the 1930 unthinned plots. The yield performances of the unthinned plats brought out the fact that a larger number of bolls, and consequently a greater seed yield, could be produced per unit of area with the close rather than with the more distant spacings. This agrees with results obtained from rate of seeding tests conducted at the South Dakota Agricultural Experiment Station, as reported by Hume, *et al.* (2).[3]

No very comprehensive data on the effects of environmental conditions on the weight and number of seeds per boll, other than differences in the amount of space for the development of individual plants, are available. According to Robbins (5), the maximum number of seeds that can be produced per boll, since "the flax fruit is a five-celled capsule with two seeds in each cell," is ten.

Sanders (7), in growing flax under greenhouse conditions on Barnes silt loam with different moisture contents, found an increase in the number of seeds per boll with increase in soil moisture. At 20% of saturation an average number of 3.27 seeds per boll was produced, as compared to 7.47 seeds per boll at 30% of saturation. Although the highest yield of flax was obtained at 60% of saturation, there were no further increases in the number of seeds per boll beyond the 30% point. The increases in seed yield per pot beyond the 30% of saturation were due entirely to increases in number of bolls per plant and corresponding decreases in the number of sterile flowers.

Dillman (1) reports that flax grown at Mandan, North Dakota, during the dry season of 1926, averaged only 3.8 seeds per boll as compared to 8.9 seeds per boll in 1927 when moisture was more abundant. Differences in soil and climatic conditions, no doubt, affect not only the number of seeds produced per boll but also the degree of plumpness and the weight of the seed.

Kuhnert (4) states that flax weighing less than 4.5 grams per 1,000 seeds should not be used for seed. This same writer refers to the weight per 1,000 seeds of 100 samples of flax collected by the Hamburg

[3]Reference by number is to "Literature Cited," p. 17.

Botanical Institute from the Province of Schleswig-Holstein. The weights of these samples varied from 4.8 to 6.1 grams per ,0001 seeds with most of them weighing more than 5.0 grams. The size and the weight of the seed is, of course, determined to a great extent by varietal characteristics. The average weight of 1,000 seeds from the 1929 spacing plats, when the small-seeded North Dakota Resistant No. 114 variety was used, was 3.79, as compared to a weight of 4.79 grams from the seed of the 1930 plats when the large-seeded Bison was used.

According to Weaver (8), flax is recognized as a "shallow and poorly rooted crop." The root habits of this crop, no doubt, have much to do with its behavior on the different plats with variation in space available per plant. Table 3, compiled from Rotmistroff's work (6), on "the nature of drought" gives evidence of the limited root system of flax as compared to the root systems of other commonly grown field crops. Table 3 gives the depth (penetration) and spread (greatest width) of the root systems of the respective crops

TABLE 3.—*Depth, spread, and coefficient of the root systems of common field crops at the beginning of flowering and the beginning of ripening.**

Crop	At the beginning of flowering			At the beginning of ripening		
	Depth, cm	Spread, cm	Coefficient†	Depth, cm	Spread, cm	Coefficient†
Winter wheat	100	78	7,800	116	126	14,614
Winter rye	90	74	6,660	130	92	11,960
Winter barley	120	110	13,200	120	110	13,200
Two-rowed barley	120	90	10,800	120	90	10,800
Six-rowed barley	100	72	7,200	110	72	7,920
Durum wheat	103	84	8,652	103	104	10,712
Oats	107	86	9,202	110	94	10,340
Millet	105	110	11,550	105	110	11,550
Corn	112	134	15,008	113	134	15,142
Flax	72	50	3,600	105	64	6,720

*Compiled from Rotmistroff (6).
†Product of the depth by the spread.

tabulated. It also gives the coefficient of the root system. For this Rotmistroff uses simply the product of the depth by the spread. It will be observed that the depth as well as the spread of the root system of flax at flowering time is much less than that of any other crop listed. At the ripening period the depth of flax roots compares somewhat more favorably with those of the other crops than at the earlier periods, yet the spread is decidedly less than that of any other crop listed, and as a result the coefficient of its root system is low. Due to the inability of the roots of the flax plant to attain as great a spread as those of the cereal crops, the available moisture in the soil

could not be utilized to the fullest extent by the plants on the more distant spacing plats. Yet, the amount of moisture at the disposal of the plants on the closely spaced plats, in the two seasons ofl the test was not reduced to the extent that it interfered appreciaby with, seed formation and development.

Klages (3) pointed out that the limited root system of the flax plant, causing it to be more or less dependent on surface moisture, accounted in part for the high variability in the seasonal yields of this crop in the central portion of South Dakota.

SUMMARY

North Dakota Resistant No. 114 and Bison flax were grown in 6-inch drill rows at intervals ranging from unthinned plants at the rate of 21 to 22 per foot of drill row to 1½, 3, 6, 9, 12, and 15 inches between plants in the drill rows.

Seed yields per plat decreased in much the same proportion as the number of plants per foot of drill row. Correlation studies between number of plants per drill row and yield of seed gave values of $r = .940 \pm .035$ and $r = .729 \pm .060$ for the seasons of 1929 and 1930, respectively.

Very close spacings, as in the unthinned plats, served materially to reduce the height of plants. However, there were no appreciable differences in the height of plants from the 1½- to the 15-inch spacings.

Uninterrupted increases were found in the number of stems per plant from the denser to the thinner stands. Such increases were greatest from the unthinned plats to those of the more immediate spacings. Correlation studies between number of stems per plant and number of plants per drill row gave values of $r = -.982 \pm .011$ in 1929 and $r = -.863 \pm .032$ in 1930.

The number of secondary branches per plant increased materially with increase in space per plant up to the 6-inch spacing, from there the increase in the number of these branches was small. Correlations between number of secondary branches per plant and number of plants per drill row gave values of $r = -.835 \pm .038$.

The number of bolls per plant increased at a rather consistent rate with increase in space available per plant. Correlations between number of bolls per plant and number of plants per row gave values of $r = -.855 \pm .081$ in 1929 and $r = .805 \pm .045$ in 1930.

High positive correlations were found between number of bolls per plant and yield of seed per plant, with values for r of $.996 \pm .004$ and $.995 \pm .001$ for 1929 and 1930, respectively.

The weight per plant and the yield of seed per plant increased rapidly with increase in space for development. Close positive correlations were found between total weights and weight of seed per plant, the values being .999 ± .001 and .993 ± .002 for 1929 and 1930, respectively. Negative correlations to the extent of — .881 ± .067 and — .814 ± .043 were found between yield of seed per plant and number of plants per drill row for the two respective seasons of the test.

The number and weight of seeds per boll were not influenced to any appreciable extent by differences in spacings. Correlation studies between weight of seed per boll and number of plants per drill row gave values of .000 and .061 ± .127 for the 1929 and 1930 plats, respectively. The relatively high yields of flax on the closely spaced plats were due to the ability of the plants to produce at the close spacings a greater number of bolls per unit of area than at the more distant spacing, while the number of seeds per boll and the weight per seed remained practically constant.

Differences in space available to the plants had no consistent influence on the oil content of the seed.

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AGRONOMIC TRIALS WITH REED CANARY GRASS[1]

F. S. WILKINS and H. D. HUGHES[2]

Alway (1)[3] cites 17 references in a paper in which he discusses the early history of reed canary grass (*Phalaris arundinacea* L.). He states that the first mention of the grass as a forage plant appears to have been made in Sweden in 1749.

Piper (8) states that the grass is a native of the temperate regions of Europe, Asia, and North America and that it grows naturally in wet soils, especially river bottoms and lake shores subject to periods of inundation. Bews (5) says that it is a hygrophilous species very wide spread in both hemispheres. Hitchcock (6) states that it furnishes an excellent quality of wild hay, and that in the northern portion of the United States it is one of the most important constituents of marsh lands. Pammel, *et al.* (7), in 1901, stated that while the grass is native in low ground, it succeeds admirably under cultivation even in dry soils and resists drouth as well as any grass under cultivation

The grass has been cultivated only to a limited extent in the United States, largely due to the fact that the seed shatters as it ripens making harvest more or less difficult and the seed costly. Schoth (9) and Arny, *et al* (3, 4) give recommendations for culture and use of the grass for the Pacific Northwest and for Minnesota sections, respectively; and Alway and Nesom (2) and Arny, *et al.* (4) give analyses for protein content of the grass at different stages of development.

STRAIN COMPARISONS

Piper (8) has called attention to the fact that the grass is decidedly variable and that about 10 strains were grown for several years at Arlington Farm, Virginia. Schoth, of the U. S. Dept. of Agriculture, working at the Oregon Experiment Station, has made segregations, one of which shatters its seed appreciably less than the ordinary strain.

Selection studies at the Iowa Experiment Station were begun with the progeny from a packet of seed received by the station from an Iowa farmer in 1918.

[1]Contribution from the Farm Crops Sub-section, Iowa Agricultural Experiment Station, Ames, Iowa. Published with the approval of the Director. Received for publication May 16, 1931.

[2]Assistant Chief in Forage Crops and Chief in Farm Crops, respectively.

[3]Reference by number is to "Literature Cited," p. 28.

Nothing is known of the original source of this seed. There were no apparent differences in plantings made with composite Iowa seed and with seed from a Pacific Northwest seed house compared through the three years of 1928–30. Using Iowa seed, a nursery planting was made in 1921 with the plants in 2½-foot hills. Seeding was in the early spring and by late fall when transfers were made sods were 6 to 10 inches in diameter. The 188 selections from this nursery were studied through a 3-year period following which 15 were tested in duplicate square rod plats through another 3-year period. The selections varied in nearly all conceivable characteristics. Final choice of three selections was based largely upon seeding habit, vigor of growth and stooling, leafiness, and drouth resistance It is believed that the inherent characteristic to set an abundance of seed is of prime importance since a majority of the original 188 selections developed very few seed heads after the first 2 years following transfer to the new location.

Three selections were increased to approximately one-sixth of an acre each, from which the first seed was harvested in 1929. There were marked differences in the yield and weight per bushel of the seed. The three strains yielded 204, 127, and 102 pounds of seed per acre which weighed 30.7, 35.9, and 28.4 pounds per bushel, respectively. Seed of the strain which gave the highest yield was distributed to Iowa farmers in the spring of 1930 under the name Iowa Phalaris.

Increases through the various steps were made vegetatively by dividing sods and transferring pieces, approximately 4 inches square, set 2½ feet apart. Transfers were made in late fall and the loss was negligible. The hills largely grew together by the end of the second season, but selections varied greatly in rate of spreading.

COMPARISON WITH OTHER GRASSES

Reed canary, timothy (*Phleum pratense*), smooth brome (*Bromus inermis*), tall meadow oat (*Arrhenatherum elatius*), redtop (*Agrostis alba*), meadow fescue (*Festuca elatior*), orchard (*Dactylis glomerata*), and English rye grass (*Lolium perenne*) were compared for yield of hay during the 4-year period of 1925–28, inclusive. The test was discontinued after the first crop was removed in 1928.

Seedings were made in upland soil, in quadruplicate plats, with timothy as a check on each fifth plat. Marked differences between the marginal and central portions of plats of some of the grasses were apparent. The heavy marginal growth for the reed canary grass was particularly pronounced. Therefore, 2-foot borders from sides and ends of all plats were removed before obtaining yields. Forage was weighed green and yields calculated for 12% moisture.

English rye grass winterkilled the first winter after seeding. Yields for the other seven are shown in Table 1. As an average for the 4-year period, reed canary grass yielded 2.06 tons per acre, whereas its nearest competitors, smooth brome and timothy, yielded only 70% as much, or 1.45 and 1.44 tons, respectively. These were followed in order by tall meadow oat, red top, meadow fescue, and orchard grass with yields of 1.39, 1.18, 0.98, and 0.83 tons per acre, respectively.

The yields of 1927 are particularly important because of the unusually dry weather which prevailed the greater part of the growing season. Even sudan grass in this field made only half of its normal production. However, in spite of the known adaptation of reed canary grass to low, fertile, undrained soils, the yield under these apparently adverse conditions was 2.99 tons per acre (total of two crops) or nearly twice as much as that of smooth brome which was second in yield.

TABLE 1.—*Yields of reed canary and of six common hay grasses, in tons per acre, 1925–28.*

Name	First crop		Second crop		Total	
	Ave. 1925–28	% of reed canary	Ave. 1925–27	% of reed canary	Ave. 1925–28	% of reed canary
Reed canary	1.51	100	0.72	100	2.06	100
Brome	1.27	84	0.24	33	1.45	70
Timothy	1.12	74	0.42	58	1.44	70
Tall meadow oat	0.93	62	0.61	85	1.39	67
Red top	0.95	63	0.30	42	1.18	57
Meadow fescue	0.70	46	0.37	51	0.98	48
Orchard	0.56	37	0.36	50	0.83	40

The first crop reed canary grass gave much the largest yield of the 4 years in 1927 despite the acute shortage of precipitation. The height of this grass to the top of the leafy growth at the time of removing the first crop was 10 inches in 1925, 12 inches in 1926, 26 inches in 1927, and 14 inches in 1928. It is believed that as a usual thing maximum yields of the grass will not be secured before the second or third year.

During the critical drouth period of 1930, reed canary grass was much more drouth resistant than 12 other species of grasses and 5 species of legumes, except alfalfa, which were growing in comparison in the same fields.

There has been a rather strong tendency for well-sodded fields of reed canary grass at the Iowa Experiment Station to become "sod bound," with greatly reduced yields, both of forage and seed, resulting. July 29, 1929, duplicate strips of an old sod were fertilized

with 125 pounds of sodium nitrate per acre, other areas receiving the same amounts of nitrogen but in the form either of urea or nitrophoska. The application was repeated in the early spring of 1930. Fertilized strips were separated by untreated strips of similar width. Although some stimulation in growth of the fertilized reed canary grass was apparent soon after the first application, fertilized areas produced but little more forage and no more heads in 1930 than did those unfertilized.

ERADICATION

In early May of 1924 heavy reed canary grass sod was plowed with an ordinary moldboard plow, following which it was disked as though in preparation for a cultivated crop. Another disking a few weeks later was effective in killing all of the grass.

In 1928 four plats each of reed canary and six other perennial grasses, previously mentioned, were plowed July 16 following the removal of the first crops. The reed canary was eradicated as easily as the other common grasses, while the usual difficulty was experienced in exterminating patches of quack grass which had gotten a foothold on some of these plats.

PALATABILITY

In 1926 reed canary grass hay harvested 10 days after the seed was ripe was fed the following winter to a group of brood mares in comparison with good quality timothy hay, and was entirely consumed before the timothy was touched.

Pure seedings of reed canary and 12 other species of grasses and 5 species of legumes grown in triplicate plantings were pastured with cows from May 21 to July 15, 1930, to compare them in palatability. With abundant other mixed pasturage in the 3-acre field, the six cows ate moderately and apparently about equally of the seven grasses, including reed canary, Kentucky bluegrass (*Poa pratensis*), red-top, tall meadow oat, slender wheat (*Agropyron tenerum*), crested wheat (*Agropyron crestatum*), and rough-stalked meadow (*Poa trivialis*). Of the 13 grasses, Canada bluegrass (*Poa compressa*), smooth brome, and timothy were preferred and timothy was eaten less than the other two. Orchard grass and meadow fescue ranked far below the group which included reed canary grass. The cows ate the least of the grasses sold commercially under the names of creeping, sheep's, chewing's, and red fescue (*Festuca*, sp.). These grasses, which appeared to be identical, were scarcely touched. If pasturing had begun 2 or 3 weeks earlier, it is probable that somewhat different results might have been obtained.

Medium red (*Trifolium pratense*) and alsike (*T. hybridum*) clovers were eaten in preference to all other species of legumes and grasses. Alfalfa (*Medicago sativa*), white dutch clover (*T. repens*), and wild white clover (*T. repens sylvestre*) were equal to the most preferable of the grasses.

MIXED SEEDINGS WITH OTHER SPECIES

Reed canary grass was seeded in a mixture with other grasses and legumes in triplicate 1/10 acre plats in upland soil in 1928. The per acre seeding consisted of 1.5 pounds each of white dutch and alsike clover, 3 pounds each of medium red and biennial yellow sweet clover, 2 pounds of timothy, and 3 pounds each of reed canary and Kentucky bluegrass.

In 1929, the biennial yellow sweet and medium red clover comprised an estimated 99% of the forage mixture for the first crop, while a trace of each of the other ingredients was distinguishable. For the second crop there was no sweet clover, while grass comprised an estimated 40% of the forage mixture and reed canary was most conspicuous of the grasses. The mixed hay yields were 2.72 tons per acre for the first crop and 1.47 tons for the second.

Through the cooperation of J. M. Aikman and his graduate assistant, H. F. Eisele, duplicate, list square meter quadrat records were obtained on each plat on November 1, 1929, at which time average counts showed 23 plants of medium red clover, 14 alsike, 9 white dutch, 0 yellow sweet, 37 timothy, 38 Kentucky bluegrass, and 11 reed canary grass.

Winterkilling during 1929–30 was *nil*. The forage of duplicate square meter quadrat areas was harvested May 24, 1930, by Mr. Eisele. A yield of 1.42 tons of hay per acre was indicated. The hay mixture contained 20% reed canary grass, 29% Kentucky bluegrass, 31% timothy, and 20% mixed clover. Following two winters of heavy snow covering, medium red and alsike clovers seeded in 1928 had persisted.

From May 21 to July 15 the 3-acre field of which these plats were a part was pastured with six cows. Because of extreme heat and drouth there was practically no further growth following removal of the cows until September 25. In late fall it was estimated that Kentucky bluegrass comprised 60% of the cover and reed canary grass and timothy each 20%. The clovers had all been killed by the heat and drouth.

Two series of seedings in triplicate 1/100 acre plats were made in another upland field the same year (1928). In 1929, the forage

in one series was cut five times and for the other twice. Estimates made July 8 previous to removing the first crop from the two-crop plats indicated that biennial yellow and medium red clover comprised 90% of the forage mixture from the height of a mower cutter-bar, alsike clover and timothy each 4%, reed canary grass 2%, and white dutch clover and Kentucky bluegrass each a trace. The total seasonal yields of dry hay per acre were 2.87 and 4.23 tons, respectively, for the five- and two-crop plats.

In 1930, the forage of duplicate square meter quadrats was harvested close to the ground and species separated from each plat. The most significant fact is that reed canary grass comprised 32% of the dry forage mixture and Kentucky bluegrass only 10% for the plats cut twice in 1929 as contrasted with 30% of Kentucky bluegrass and no reed canary for the plats harvested five times. These figures are for two cuttings harvested from the five-crop plats and one from the two-crop plats. After these crops were removed growth practically ceased for the season because of the critical drouth. The total yield of the two cuttings for the five-crop plats was 1.23 tons of dry forage per acre composed of 36% timothy, 38% Kentucky bluegrass, and 26% of medium red, alsike, and white dutch clovers combined. The two biennial clovers had persisted into the second crop year in this field also. The yield of one cutting from the two-crop plats was 1 07 tons per acre and was composed of 32% reed canary grass, 10% Kentucky bluegrass, 46% timothy, and 12% mixed clovers.

The clovers were all killed by the drouth, but satisfactory stands of grasses remained after the latter were revived by fall rains. In late fall Kentucky bluegrass comprised an estimated 95% of the cover of five-crop plats and only 40% of two-crop plats. Practically no reed canary grass and timothy remained on five-crop plats, while for two-crop plats the remaining 60% of cover consisted about equally of reed canary grass and timothy.

GROWTH IN KENTUCKY BLUEGRASS PASTURES

In 1922, sods were set in a slight depression of an upland Kentucky bluegrass pasture. Poor drainage prevented the growth of local species and the area was bare when the reed canary grass was started.

The depression, situated among trees, is shaded part of the day. The sods set 2 feet apart formed a heavy turf which is still in vigorous condition, the reed canary grass completely dominating the area, though entirely surrounded by Kentucky bluegrass on higher ground.

In 1922, 1/20 acre of Kentucky bluegrass sod in a low but fairly well-drained area adjacent to a creek was plowed and disked. Reed

canary grass sods were set 2 feet apart. The retarded but unkilled Kentucky bluegrass soon furnished plentiful competition. Apparently the cover has been rather constant for some years. Reed canary grass and Kentucky bluegrass are intermingled, with the former constituting about 80% of the cover.

A typical side hill Kentucky bluegrass pasture, low in organic matter, was thoroughly disked in the early spring of 1922 and seeded with reed canary grass at the rate of 15 pounds per acre. An excellent stand of the grass was obtained, but much Kentucky bluegrass was not killed so that the reed canary grass seedlings were soon given severe competition. Reed canary grass was replaced gradually by Kentucky bluegrass so that at the end of four years but little of the latter remained.

TIME OF SEED HARVEST

The individual seeds of reed canary grass ripen rapidly and shatter almost as soon as fully ripe. Ripening progresses from the tipmost spikelets of rachis and branches. Since the ripening period extends over several days, it is necessary to harvest after some of the seed has shattered in order to obtain the maximum yields of germinable seed.

In 1929, seed was harvested through an 8-day period, beginning June 22, to determine the most satisfactory stage of development. Bundles with similar numbers of heads were collected in the morning of each day, transported in tarpaulins, and dried in the laboratory so as to recover all seed. Estimates of stages of development made each morning, similar to those a grower would make, are shown in Table 2 which also gives comparisons of the threshed seed free from inert materials.

When the test was begun June 22 the development of seeds of individual panicles ranged between late water to late hard dough. Ripening then progressed rapidly and three days later, June 25, an estimated 1% of the ripe seed had shattered. The highest yield of 246 pounds per acre was obtained for the harvest of June 26 by which time it was estimated that 5% of the seed had shattered. The yields increased from 170 pounds per acre for the first day, June 22, and receded to 146 pounds for the last day, June 29, when the estimated amount of shattering was 50%.

Weight per bushel of the seed increased consistently from 24 pounds for June 22 to 36.5 pounds for June 29. However, for the last three days, June 27, 28, and 29, there was but little difference since the weights for those days in order were 36.0, 36.1, and 36.5 pounds. For June 26, when the maximum yield was obtained, the weight per bushel was 33 pounds.

TABLE 2.—*Effect of time of harvesting reed canary grass upon the yield and quality of the seed.*

Date harvested, June	Yield, lbs. per acre	Weight, lbs. per bushel	Thousands of seeds per lb.	Color of seeds			Germination			
				Light %	Medium %	Dark %	Light %	Medium %	Dark %	Composite %
22	170	24.0	1,030	57	35	8	9	89	96	45
23	216	26.8	812	38	35	27	16	91	99	65
24	203	29.7	767	22	25	53	26	93	99	81
25	203	32.6	714	14	22	64	24	85	99	86
26	246	33.0	709	10	19	71	23	98	99	91
27	216	36.0	659	12	16	72	23	88	99	88
28	189	36.1	632	10	14	76	42	81	97	89
29	146	36.5	658	8	11	81	17	74	98	89

Stage of development by days in June (pre-harvest estimates):

22—Late water to late hard dough.
23—Few ripe seeds in extreme tips of ripest heads.
24—Seeds in tips of heads generally ripe.
25—1% shattered; 25% ripe.
26— 5% shattered; 40% of remaining seed ripe.
27—10% shattered; 60% of remaining seed ripe.
28—40% shattered; 75% of remaining seed ripe.
29—50% shattered; 80% of remaining seed ripe.

Consistent with advanced development and weights per bushel the number of seeds per pound decreased progressively from June 22 when there were 1,030,000 to June 28 when there were 632,000 per pound. The slight increase to 658,000 for June 29 is inconsistent. However, counts for triplicate 0.1 gram samples check closely throughout.

As explained and illustrated by Arny, *et al.* (4), who report work of a similar nature, seeds threshed from a single panicle vary in color from entirely brown or gray to those with little or no dark color in the palea and lemma. For seed grown at the Iowa Experiment Station gray strongly predominates over brown in the individual seed which becomes darker with advanced maturity.

Three hundred seeds taken from the harvest of each day were separated into groups of light, medium, and dark color. The percentage of dark seeds increased from 8 for June 22 to 81 for June 29 with 71 for the optimum date of harvest. Likewise, the percentages of light and medium colored seeds decreased with advanced dates of harvest.

The germination of the composite of 300 seeds increased from 45% for June 22 to 91% for June 26, the optimum date of harvest, and was practically similar for the last 3 days.

The germination of dark seeds was high, between 96% and 99% for each date of harvest. The viability of seeds medium in color varied from 74% and 81% to 98% for different dates with seeds of the optimum date germinating highest, probably by chance.

The weighted mean germination of all light seed is 18%. Light seeds harvested from June 24 to 27, inclusive, germinated uniformly between 23% and 26%. Seeds light in color for the June 22 and 23 harvests germinated 9% and 16%, respectively. The weighted mean germination of light seeds harvested June 28 and 29 is 31%. The inconsistency of the separate tests for the two last dates is no doubt due to small numbers.

SHOCK COVERS PREVENT SHATTERING LOSS

In 1929 and 1930, the heads of eight-bundle shocks were covered with burlap sacks and tied securely. The grass had been cut as high as possible with the grain binder when the tipmost seeds of panicles were ripe. The sacks were entirely effective in preventing loss of shattered seed and in no way interfered with curing despite incessant rains in 1929. Seed cured in this way germinated 93% which was equal to seed harvested by hand and dried in the laboratory.

HAY YIELDS FOLLOWING SEED HARVEST

When the seed crop of a productive turf is cut as high as possible with a grain binder most of the leaves are harvested and the remaining stubble is of little value for hay.

In 1929 and 1930, following harvest of seed crops with a grain binder, tests were conducted to measure the effect of removing the stubble upon the subsequent crop of hay. A high stubble was left when cutting with the binder as an aid in reducing the loss of seed by shattering as well as to reduce the amount of straw handled.

Stubble remaining after cutting the seed crops June 22, 1929, and June 23, 1930, was 16 inches high Immediately after seed harvest duplicate 1/30 acre plats were cut at ordinary mower height with yields determined while triplicate plats were left uncut. October 2, 1929, and September 22, 1930, hay yields were determined for all plats. Forage was weighed green and yields calculated for 12% moisture.

In 1929 the yield of stubble was 1.25 tons per acre and the subsequent yield of hay was 1.86 tons. The forage yield of plats left uncut following seed harvest was 2.90 tons Heavy rainfall accounted for the high yields that developed after seed harvest.

In 1930, a severe drouth followed seed harvest. Stubble yielded 1.12 tons per acre and the subsequent yield of hay was 0.38 ton. The forage yield for uncut plats was 1 18 tons per acre.

The net yields of quality hay after deducting for the yields of stubble from uncut plats were in favor of removing the stubble in each of the 2 years. They favored removing the stubble by 0.21 ton per acre in 1929 and 0 32 ton in 1930.

SUMMARY

Plants of reed canary grass vary greatly in habit of growth. From 188 selections made in 1921 a single selection was distributed to Iowa farmers in 1930 under the name Iowa Phalaris.

The average annual hay yields, in tons per acre, of seven grasses, for a 4-year period were as follows: Reed canary, 2.06; smooth brome, 1.45; timothy, 1.44; tall meadow oat, 1.39; red top, 1.18; meadow fescue 0.98; and orchard, 0.83.

Reed canary was eradicated as easily as any of the six other species.

Reed canary was more drouth resistant than any of the others in 1927. In 1930 it was more drouth resistant than 12 grasses and 4 out of 5 legumes with which it was compared.

In a palatability trial with horses reed canary grass hay harvested after the seed was ripe was consumed in preference to a good quality of timothy. In pasture trials with cows reed canary was

equal in palatability to six other grasses, including Kentucky bluegrass. Canada bluegrass, smooth brome, and timothy were superior, while orchard and the fescue grasses were inferior.

Frequent, close cutting of seedings of reed canary grass on an upland soil, in mixtures with other grasses including Kentucky bluegrass, resulted in an increase in the proportion of bluegrass. This did not result when cuttings were less frequent.

In established Kentucky bluegrass pasture on bottom soil well supplied with moisture, reed canary grass has maintained itself satisfactorily, but it has not done so on upland soil.

In a trial conducted in 1929 the largest yield of seed and the best quality were secured when harvest was delayed until approximately 5% of the seed had shattered.

When seed crops were harvested with a grain binder burlap sacks used as shock covers were effective in preventing loss from shattering and did not lower the quality of the seed.

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PUTTING FIRST THINGS FIRST IN AGRONOMY[1]

F. J. SIEVERS[2]

The history of science, and especially of chemistry, offers numerous illustrations of investigators allowing their enthusiasms to carry them far beyond the limits where there is any reasonable assurance of success. A case in point is the attempt to find a universal solvent—a liquid that will dissolve anything. It is conceivable that endeavor to reach this goal might have been continued even to this day had not some one of a practical turn of mind raised the question, "What will you keep it in when you do find it?"

Although results of this type are not very encouraging to the individual investigator, they are fortunately not a total loss to the cause of research. Even though the universal solvent proved elusive, the intensive efforts to produce it no doubt contributed very liberally toward the development of the science. In spite of these values, however, there is a limit beyond which investigation without the direction of real sound vision or imagination should not proceed. It is well, therefore, that the research worker be aroused from time to time to take stock and thus assure himself that he has not become sidetracked while the real procession is going by on the main line.

Investigators in agronomy, and especially in soil science, have not been free from riding these hobbies. In the field of soil acidity we have frequently put the entire emphasis on methods of accurate determination, without any apparent interest in its significance in terms of agriculture. Many base-exchange studies can be charged with this same criticism. The dust-mulch enthusiasts have had their day. Complete soil analysis as a basis for fertilizer applications is no longer taken seriously, although the author is here to testify to its value in exposing the laboratory worker to an opportunity for the assimilation of liberal quantities of both theoretical and technical chemistry. The bank-check-book system of maintaining soil fertility, so ardently preached not many years ago, when found to be of greater mathematical than agricultural interest rapidly went by the board. Even in field plat work it is not uncommon to go to extremes in perfecting methods of accuracy for measuring differences in yields without any apparent concern about the cause or even significance of such differences in terms of practical or scientific agriculture.

In recent years the writer's interest has been much centered in those

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[2]Director.

investigations dealing with the maintenance of soil organic matter. There are indications that many workers in this field assume that it is of primary importance to maintain the soil organic matter, and they proceed with detailed research on that basis. As a matter of fact, however, there is no more justification for this assumption than there was for the conclusion so generally accepted in the past that soil fertility needs to be maintained. Successful agriculture may not be, and evidently is not, primarily dependent upon maintaining either, unless there is definite evidence that the methods involved are economically sound. Successful agriculture is dependent upon the maintenance of productivity.

Because of the constancy of the relationship between the nitrogen and organic matter in productive soils as evidenced by results from numerous analyses, the writer has frequently expressed (1, 2, 3, 4, 5)[3] the theory that there can be no increase in effective soil organic matter without first a proportionate increase in soil nitrogen; and that, furthermore, if by artificial means the constancy of this ratio were upset, this would be reflected in decreased yields. Such an upset in the ratio might be brought about either by the partial depletion of fertility and consequently of nitrogen through cropping, or by the application of excessive amounts of high carbon organic matter. In either case the desirable balance between nitrogen and organic matter would have to be re-established before satisfactory yields could be expected to follow. In cases of depleted fertility, plant food, and especially nitrogen, would need to be applied; and when there is an excess of high carbon organic matter, there must be provision for the elimination of this carbon through the encouragement of decomposition processes. From this one would be led to conclude that under conditions of practical agriculture provision for the maintenance of yield will automatically dispose of any soil organic matter problems.

Although this theory could be substantiated on data that had become available during a comparatively short period of definitely controlled investigation, there was a strong desire to know what would follow if these conclusions were actually put to test in field practice over a long period of years. The plats at the Pennsylvania Agricultural Experiment Station offered this opportunity through data presented by J. W. White (6) of that Station, and reproduced here in Table 1. These plats are the oldest in the United States from the standpoint of continuous records (49 years) under the same treatment.

[3]Reference by number is to "Literature Cited," p. 32.

Whatever else Table 1 may show, the evidence is conclusive that while the total organic matter accumulation may be highest for those plats treated with organic fertilizers, manure in this case, comparative yields do not indicate that this organic matter was necessarily very effective. The complete fertilizer treatments without manure produced as high, if not slightly higher, yields than the manured plats, and apparently provided the essentials for a measurable increase in the soil organic matter. It is even conceivable that on the manured plats the rate of organic matter accumulation has

TABLE 1. *Relation of yields to residual soil organic matter.*

Plat treatment	Yield-organic matter ratio*	Untreated soil as 100	
		Plat yields	Soil organic matter
N (24 lbs. N, dried blood)	916	99	91
Untreated	992	100	100
K	958	100	97
Land plaster	892	104	93
Burnt lime	932	111	104
KN (24 lbs. N, dried blood)	878	112	99
Limestone	818	120	99
P	762	126	97
PN (24 lbs. N, dried blood)	698	144	101
PK+72 lbs. N (ammonium sulfate)	770	146	113
PK+48 lbs. N (ammonium sulfate)	718	159	115
PK+24 lbs. N (dried blood)	716	163	118
PK+24 lbs. N (ammonium sulfate)	668	164	110
PK	654	175	116
PK+24 lbs. N (nitrate of soda)	664	176	117
PK+48 lbs. N (nitrate of soda)	614	181	112
PK+72 lbs. N (dried blood)	650	181	119
PK+72 lbs. N (nitrate of soda)	616	184	114
6 tons manure	774	167	131
8 tons manure	764	172	132
6 tons manure+lime (CaO)	718	180	131
10 tons manure	760	181	138

*Organic matter ratio = Pounds organic matter per ton of total air-dry matter produced in 40 years.

been in excess of the accumulation of nitrogen and other plant food constituents, and that larger yields might be obtained if the manured plats were to go untreated or if an inorganic complete fertilizer were used for the next several years, thus affording an opportunity through decomposition for the proper nitrogen-organic matter ratio to become re-established. Certainly there is no evidence that the treatment producing the largest accumulation of organic matter produced the best yields. It would seem, therefore, that the time is here when we

should take a turn about and ask the question, "What to do with this organic matter after we have it?"

Instead of placing our primary and major emphasis on determining in minute detail the processes involved in soil organic matter maintenance, we had better find the soil treatment necessary to produce the best and most profitable yield and feel secure that the greater supply of crop residues resulting from large yields will automatically provide soil organic matter in amounts adequate to satisfy all normal demands. As tangible evidence that this conclusion is practical and logical there is the case of the truck farmer who, when denied opportunity to avail himself of animal manures, has substituted commercial fertilizers with entirely satisfactory results. Better still, the Connecticut Valley tobacco grower, farming on soil primarily very poorly supplied with organic matter, has been so successful in maintaining yields with commercial fertilizers as the only source of plant food applied that he would not now use animal manure on his soil even if it could be obtained.

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RUSSIAN STUDIES ON SOIL PROFILES[1]

J. S. Joffe[2]

(Editor's Note: Although review papers are not generally acceptable for publication in this Journal, an exception has been made in this instance in the belief that information on Russian literature on this subject would be welcomed by many readers of the Journal who otherwise might find this literature unavailable.)

The soil profile as it reveals itself in a vertical cut of a virgin soil with the characteristic build and constitution of the layers, known as horizons, is the alpha and omega of the Russian system of soil studies.

The specificity of the soil profile, its morphologic features and characters, its uniqueness for any particular climatic zone, and hence its uniform geographic distribution served as the basis upon which the founders of the Russian school of soil science—Dokuchaev, Sibirtzev, and their followers—have developed and built the concept of the soil as an independent natural body. A logical outcome of this concept was the development of soil science as an independent branch of science in the family tree of the natural sciences.

Soil science recognizes the soil as a distinct organism with definite morphologic and constitutional (physiological) features, with specific physical properties, chemical composition, and biological make-up. It is the soil body as found in nature, its anatomy and physiology, its behavior towards the forces which are responsible for its creation that concern soil science. The principles underlying the elucidation of the natural sciences are applicable also to soil science. For the study of soils the fundamental sciences—chemistry, physics, and biology—provide methods and guiding, basic laws.

Until the advent of the Russian school of soil science, the object studied by soil investigators was the mass of the soil body, the soil material. Most, if not all, of the accumulated knowledge about the soil was obtained from observations, analyses, and experiments with the soil material; and the underlying motive of soil studies was the desire to learn how to increase the productivity of the soil.

A deeper insight into the riddles of the soil was made possible only after the science got on its own feet and began to apply the

[1]Contribution from the Department of Soil Chemistry and Bacteriology, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Also presented as part of a joint symposium by the American Society of Agronomy and the American Soil Survey Association in Washington, D. C., November, 1930. Received for publication May 25, 1931.

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scientific methods of study and the principles of the fundamental sciences.

Like any other of the natural sciences, soil science began with the descriptive phase. The soil body was dissected, cut open vertically, and the exposed anatomy noted and described. In a natural state it revealed, as pointed out, a definite construction or build, consisting of distinct horizons, which are specific in their morphological, physical, and chemical characters, irrespective of the geographic position of the soil, its underlying geologic formation, provided it is located in identical climatic zones. The horizons exposed in a vertical cut of the soil body are genetically related and as a unit they represent the soil profile.

The principle of the geographicity of the soil was known before Dokuchaev announced to the world his comprehensive deductions about the geographic distribution of soil types. Thus Richthofen (27),[3] the famous German geographer and geologist, whose travels through China, India, Ceylon, and other parts of the world gave him the opportunity to observe various types of soils, recognized the correlation between the environment—with respect to the geographic position—and the processes of rock decomposition and its formation anew. But Richthofen based all his conclusions about the regional distribution of soils on the geological features of the region. He wrote, "The entire earthy cover as well as the native rocks are objects of geological investigations. . . . Soil is a loose surface formation, a kind of a pathologic condition of the native rock."

At this point it is well to recall another fundamental idea of the Dokuchaev school of soil science, namely, that the present geography of the soil cover is closely related to the present distribution of climatic elements. The soil body is therefore a recent formation—speaking of age in geological terms. Dokuchaev cites an example of a soil formed on the wall of an old fort which was originally built from silurian limestone and granitic boulders. The soil was 10 to 12 cm deep, and from the historical records, as quoted from Glinka (14), its age was calculated to be 870 years at the time Dokuchaev examined it.

Zakharov (44, p. 252) cites the observations of Ruprecht (30) on the development of a soil profile in the mounds[4] of the chernozem

[3]Reference by number is to "Literature Cited," p. 55.

[4]The mounds in the Russian steppes are slightly elevated, artifically built-up knolls. Their origin is not very well established. It is claimed that they were guiding points for the invading Asiatic hordes that used to sweep down on Europe. Some of them served as burial grounds for the war chiefs.

belt. The area adjacent to the mounds possessed a soil 60 to 150 cm deep, whereas the one on the mound was 15 to 28 cm deep. Historical records show that these mounds were about 600 years old at the time Ruprecht examined them.

Thus the soil as a formation must be linked up with our contemporary climate, and Glinka (14) justly states, in discussing Richthofen's work,

"When one speaks of geographical position he understands the existence of a natural relation between the present distribution of climatic elements and the present geography of the soil cover. The regionality as described by Richthofen has at times no connection with the present climatic conditions. Thus the regions of glacial denudation, accumulation, river denudation, abrasions, and of volcanic transport exist on the surface of the earth entirely independently of the present climatic conditions."

Mention has been made that soil science as an independent branch of science began with the descriptive phase. In other words, the morphological principle was adopted for the studies of soils by the Russian pedologists.

Ruprecht (30) was probably the first one to apply the morphological methods in the study of soils. He described the soil profile of the chernozem type, but he failed to correlate the facts which pointed to the existence of a specific natural formation. It was left to Dokuchaev to bring out the uniqueness of the soil body as a natural object and thus soil science as an independent branch of science. One of the outstanding features of Dokuchaev's views consisted, according to Afansiev, the famous Russian soil geographer, "in excluding soils from the system of surface cover formations and placing them into a distinct independent system of natural science."

Dokuchaev succeeded in differentiating the morphological, physical, and chemical characteristics of soil types and his classical researches were unique in bringing out the facts responsible for the formation of the types. One of the theses in the summary of Dokuchaev's doctor's dissertation was, "If we know the factors of soil formation we are able to state in advance what the soil must be like." As early as 1877, Dokuchaev (5) stated,

"Whether we admit that the southwestern portion of Russia was submerged under the sea in the beginning of the post-tertiary period, as some geologists think, or it was covered by glaciers, as other geologists think, or it was dry land, as still another group of geologists think, matters little. For us it is important that after this or the other of the given phenomena the upper layers of the parent soils were apparently subject to various processes due to weathering and to processes due to vegetation; both of these were instrumental in changing the upper horizon of the parent material to a greater or

lesser depth. These parent materials which have undergone changes by the mutual activities of the air, water, and plants, I call soil."

An important link in the system of the Russian school of soil science is the differentiation of the factors in the process of soil formation. Indeed many investigators in Western Europe, long before Dokuchaev, were engaged in soil studies. They were pondering over the problem of soil fertility, but the processes of soil formation were not of primary interest to them. To them the soil was nothing more than an agronomic object of geologic origin, a kind of disintegrated, decomposed rock material with an admixture of humified organic substances. The apparent similarity between soils and geologic formations influenced the investigators to consider the soil as a geologic formation in the physiographic sense. The existence of clay deposits, lime deposits, peat deposits—purely geologic formations—brought the concept of soil, which at times could be identified with such deposits and which even bears their names (clay soils, chalk soils, peat soils, etc.) into close harmony with the science of geology. Such an approach, as well as the purely agronomic, physical, chemical, and later physico-chemical approaches, for a more detailed discussion of which see Joffe (16), was fruitless in bringing out the rôle of the various factors of soil formation. The soil as an independent object of study was unknown to Berzelius, Liebig, Walz, Thaer, Schmalz, Shcübler, Davy, Boussingault, Sprengel, and a great number of other investigators. Even Fallou who had already attacked the soil problems from a more modern point of view and recognized the soil as a formation by itself (16, 17) neglected to analyze the factors of soil formation. Only with the advent of the soil profile concept was it natural to expect that the habitus, appearance, and make-up of the soil body would be analyzed and the factors in the process of soil formation brought out and distinguished.

It was Dokuchaev who emphasized the importance of the factors in soil formation, but he took up all the factors of soil formation as a complex and did not differentiate them. It was Sibirtzev (32), one of Dokuchaev's collaborators, disciples, and followers, who established the differential rôle of the various factors in soil formation. The zonal distribution of soils as an outgrowth of the climatic zonality was developed by Sibirtzev. To him we owe also the idea of the intra-zonal soils, which explains the occurrence of the soils of a particular zone within another one where it ought not be. In recent years Afanasier (1) furthered the idea of the zonality of soils.

Sibirtzev considered moisture as the primary climatic factor in soil formation. In this his views coincide with those of Hilgard, who

divided the soils, on the basis of moisture relationships, into arid and humid. To quote Sibirtzev (31):

"More important than the temperature is the humidity of the climate. Elsewhere enough was said about the primary and manifold influence of moisture on mechanical as well as chemical weathering. It is quite clear that in any isothermic belt the weathering of rocks varies (qualitatively and quantitatively) with the moisture conditions."

In speaking of the climatic conditions in North America he stated, "The humidity of the American climate changes in an entirely different direction from that of European Russia; the loss of moisture does not follow the northwest-southeast direction, but the east and west. The eastern states are humid; the precipitation is twice as high as in our southern provinces. The western states, on the other hand, are very dry and are known among the Americans by the very inappropriate name 'arid region.' Correspondingly goes the distribution of soils."

It will be of interest to quote at this point the views of Sibirtzev as to why the new concept of soils did not develop in the West, as follows: "The causes which impeded the independent scientific study of soils in the West and prevented the establishment of a genuine genetic classification of natural soils were local, more or less accidental, due to external conditions. West-European scientists were less fortunate in this respect; in most cases they had to deal either with feebly developed soils, mixed with various geological deposits of inconsiderable thickness, or with eroded soils; and besides, the soils have changed appreciably through cultivation."

With the development of the views of Dokuchaev and Sibirtzev, the methods of studying soil have been modified. The mere sampling of soils became an art of no small importance. It was necessary to devise methods of taking a sample whereby the genetic relationships of the horizons in the soil profile should not be disturbed. An outgrowth of that was the monolith sampling. The first one to devise apparatus and to take such samples was the Russian pedologist Rizpolozhenskii (29).

Ever since Dokuchaev worked out the idea about the soil being an independent natural body, the soil profile became the starting point for the elucidation of the various soil problems.

It was observed that, in general, the profile features of the soil are essentially the same in all climatic zones. Studies of the soil anatomy have shown that any soil profile consists of three or four genetic horizons as follows: 1. the decomposition-organic-accumulative; 2. the eluvial; 3. the illuvial; and 4. the parent material immediately below the illuvial horizon. No matter what kind of a soil one examines, as long as it is a mature soil, in any climatic zone, in

any geographic region, the profile characteristics, as outlined, are to be found.

Horizons 1 and 2—the humus-accumulative and eluvial—are to be considered jointly, since the former is not a true horizon inasmuch as it consists only of the decomposed and undecomposed organic remains of the native flora. It supplies the substances for the processes of eluviation. Most of the Russian investigators designate this accumulative horizon by the letter A_0, whereas the entire eluvial horizon bears the letter A. When this horizon is divided into sub-horizons the letters A_1, A_2, etc., are used.

As mentioned, the A_0 horizon is accumulative in character. Besides the organic residues which find their origin primarily in the air and moisture regime, there are mineral substances in the organic residues which find their origin in the soil material from the lower horizons. In the mineralization process of the organic matter these substances are given up to the soil body. Part of them becomes fixed with the humus materials, and with the microbial flora, which is instrumental in the decomposition of organic matter. The rest of the mineral substances is leached downward. In this manner horizon A_0 is genetically related to the other horizons in the soil profile.

Below A_0 the horizon of eluviation is located. It is subject to the action of the decomposition products of the A_0 horizon, such as carbonic acid from respiration of roots and microbial decomposition of organic materials, nitric acid from the processes of nitrification, sulfuric acid from the processes of oxidation of sulfur compounds, other inorganic acids like phosphoric and silicic, and the organic acids from the decomposition of the organic materials. All of these acids, together with the organic and inorganic colloids, react with the mineral and organic soil constituents, dissolve them, enter into chemical combination with them, and in this manner move with the percolating waters. The intensity of the leaching reactions depends primarily on the climatic factors of the zone.

Most of the materials which are leached out from the A horizon and the products of chemical and mechanical movement are caught in the next horizon which is known as the horizon of accumulation or illuviation (washing in). It is usually designated by the letter B. The chief characteristics of this horizon are compactness and enrichment with colloids, bases, and electrolytes in general. Its functions appear to be protective. It seems as if this horizon is on the guard to preserve the soil body and prevent its destruction. If it were not for the B horizon, the soil body would become skeletal in nature and all of the soil constituents would disappear with the

ground waters. As in the case of horizon A, the type of accumulative materials, mode of deposition, intensity of reactions, and the many other characteristics of this horizon depend primarily on the climatic factors of the respective zone.

Below the B horizon comes the parent material, which is very little affected by the soil formers which go to make up the soil body with its characteristic profile. The parent material is usually designated by the letter C. Beyond a certain depth from the surface of the C horizon, the soil profile ends and the material below is to be looked upon as geologic formation.

In his extensive studies and researches on the Russian chernozem, Dokuchaev could not help but notice that this particular type of soil developed on various parent materials, such as loess, glacial drift, marine and lake sands, clays, limestone, marls, shales, sandstone, and many other geological deposits. Evaluating the importance of the various soil formers, Dokuchaev and his followers were forced to place the parent material not as the primary agent in the process of forming the soil body, but as the secondary. At present the general concensus of opinion among Russian pedologists is that the parent material is looked upon as a passive soil former, serving as the chief source of the mass for the soil body. It is the energy, however, which goes to make up the soil body in the process of soil formation, and this is furnished by the active soil formers of which the climate is the important one.

There are departures from the general behavior of the parent material as a passive soil former. At times it leaves its subordinate position and takes the upper hand, so to speak. As Neustruev (22) puts it, "Parent rocks are far from being a blank sheet of paper on which the climate may write anything it desires."

Also, Glinka (14, p. 288) points out that there are groups of soils

"where the composition of the parent material takes the upper hand over the climatic influences. This group of soils we call endodynamomorphic in contrast to the ectodynamomorphic. The endodynoamomorphic soils are a temporary formation, which might persist until the chemical composition of the parent material has changed. After such a change they are converted into soils characteristic of the zone in which they are found; thus rendzina in the podzol zone is gradually converted into a podzolized soil."

In mountainous country, especially on the slopes, endodynamomorphic soils are more apparent, since erosion washes out considerable amounts of the fine materials, and the parent material is very much in evidence in the soil body.

Although the general character of the horizons in the soil profile

is true as described, each soil zone may be distinguished by the specific features of its own profile; and it is the differences in the respective horizons of the soil profile that mark the soil zone.

First of all, the morphological differences were noted, *viz.*, the depth of the profile, its habitus, the thickness, color, and a number of other features of each horizon. Next, the physical differences in the profile were noted, including the constitution (compactness and consistency), texture, structure, concretions, and traces of the activity of burrowing animals and insects. And finally, the differences in the chemical composition of the respective horizons in the various soil zones, the translocation and movement of the various soil constituents, the state of the colloidal fraction, the base exchange capacity, and other elements of chemical behavior of the respective horizons were noted.

It would lead us too far astray if detailed analysis of the individual features in the profile of the zonal types[5] of soils should be attempted. For our purpose it will suffice to outline briefly the distinguishing characteristics of the profile in the various zonal soil types as presented by the leading representatives of the Russian school of soil science.

From the genetic point of view as worked out by this school, the grouping of the soil types has to hinge primarily on the factors of climate, but the continuity of the climatic soil zones is at times broken by local factors, such as relief, moisture conditions, and other factors which geographically place some soils into zones not typical for the climatic belt. This gives rise to the so-called intrazonal soils, which bring into the scheme of soil systematics other divisions besides the climatogenic soils. Thus we have (a) orogenic soils in which the topography is one of the dominating factors of soil formation, the mountain soils comprising this division; (b) hydrogenic soils in which the moisture movement is one of the dominating factors of soil formation, with peats, marshy soils, and alkali soils belonging to the division; (c) fluviogenic or alluvial soils in which the flood plain enters as an important factor in soil formation; and (d) lithogenic soils in which the parent material plays an important part. Of course it is the climatogenic soils which are the most important ones and to a consideration of these we shall now proceed.

Although there is no one uniform system of designating the soil zones, still the grouping of these by the leading pedologists in Russia is very much alike. Kossovich (19) divides the soils on the basis

[5]We speak of the zonal type in the sense of the type of the process of soil formation; thus we have the podzol type of soil formation, the cherozem type, etc.

of the type of soil formation, *viz.*, (a) desert type, desert pavement, dry solonetz, etc.; (b) desert steppe; (c) steppe chernozem; (d) podzol; (e) tundra; and (f) laterite.

Glinka (15) distinguishes six soil zones, *viz.*, (a) tundra, (b) podzol (forest), (c) chernozem (steppe), (d) chestnut and brown, (e) grey, and (f) laterite.

Zakharov (44), one of the leading living Russian pedologists, groups the soil zones as follows: (a) Red, humid and warm regions; (b) grey, desert and semi-desert steppe; (c) brown and chestnut brown, temperate, warm, and arid region; (d) chernozem, semi-arid, warm, and temperate region; (e) forest-steppe, temperate, cool, and semi-humid region; (f) podzol, forest region; and (g) tundra, cold and humid region.

Grey soils.—The desert and semi-desert type of soil formation is characterized by rainfall deficiency. The profile constitution of this type of soil is feebly developed. With scant vegetation, if any, there is very little chance for the formation of any humus accumulative horizon. There is also very little chance for leaching reactions. Hence the horizon of eluviation is barely noticeable. On the contrary, there is a movement of salts from the lower levels to the surface. In some cases a crust forms with $CaCO_3$ and $CaSO_4$ as the cementing agents. In other cases, a flaky crystalline mass of NaCl and Na_2SO_4 settles out and is carried away by the winds. In this unique way the soil loses appreciable quantities of easily soluble mineral salts.

"Desert crusts" have been described by Lapham (19). Wolfanger (43, p. 31) points out that these soils have a surface horizon consisting of a "thin 'desert crust' or a thin pebbly layer which forms the so-called 'desert pavement.' Its substructure, the desert mulch, is a light porous material of little compaction."

Zakharov gives the following description of a typical grey soil profile:

0–10 cm: A_1—horizon with a characteristic straw-colored grey with various shades—yellowish, brownish, reddish, pinkish;—it is of a scaly laminated structure, fairly open constitution.

10–30 cm: A_2—a transition horizon lighter in color than A_1, at times having a brownish shade, is of a spongy constitution, honey-combed with tracks of burrowing animals.

30–80 cm: B—illuviated horizon, lighter in color, usually straw colored, at times grey because of the numerous minute lime veins, more compact, with a fine porosity. White spots known as "beloglazki" (white eye spots) are frequently encountered.

80—cm: C horizon. The parent material at the surface of which sulfates and chlorides are frequently found alongside the lime carbonate.

According to Neustruev (22), a characteristic feature of this zone is the presence of $CaCO_3$ close to the surface irrespective of the parent material, be it loess, alluvial clay, conglamorate, or what not. Glinka (14, p. 550) points out that the "entire belt of the foothill country in Turkestan with its grey soils is distinguished climatically by its aridity. Less than 300 mm. (as low as 150 mm.) of rainfall is the yearly precipitation of the region with a mean annual temperature of 10°C."

The process of soil formation in the zone of grey soils goes on under alkaline conditions and for that reason these soils are, in the nomenclature of Gedroiz (9), saturated with bases.

Brown and chestnut brown soils.—There seems to be no concordant agreement among the students of the Russian school of soil science as to whether the brown soils should be separated from the chestnut brown soils as a special zone or the two combined into one zone. Although there are certain differences—color and percentage of humus are outstanding in the profile constitution of the two soil types—there seems to be not enough of these to justify the separation of two distinct zones. Glinka (14, p. 376) is inclined to separate the two into distinct zones, while Zakharov (44, p. 322) favors placing the brown and chestnut-brown into one zone. However, when it comes to describing the brown-chestnut-brown zone, Zakharov divides it into two subtypes and resorts to the same source of information for his subtypes as Glinka does for his special zones.

The brown soils differ from the chestnut brown soils in their lighter brown color, which blends into a grey. Because of this grey shade, which, by the way, is a characteristic for all the soils of the semi-arid steppe, the humus horizon of the brown soils at times cannot be differentiated from the horizon beneath it. The greyish brown shade predominates over the dark colored humus which is not too abundant in the brown soils, which on the average contain as high as 2 to 3% humus. The chestnut-brown soils contain as high as 3 to 5%.

Zakharov (44, p. 322) gives the following morphologic description of a brown soil profile:

0–15 cm: A_1—humus horizon, straw-colored grey with a brown or chestnut-brown shade, laminated structure, loose, finely porous constitution.

15–26 cm: A_2—slightly compacted, a more bright chestnut brown shade, columnar like, partly crumbly structure, slightly compacted and cracked constitution.

26–45 cm: A_3—lighter straw-colored, with brown streaks and tongue-like projections, crumbly, nutty structure, more loose constitution, with a lot of worm tracks.

45–75 cm: B—illuvial horizon, straw-colored with white spots and veins of lime carbonate, slightly prismatic, porous, and feebly cracked. Gypsum is also frequently found.

75--cm: C—loess-like or any other parent material which contains, some times, some soluble salts.

Usually effervescence begins at A_3, but infrequently the presence of carbonates could be demonstrated in the overlying horizons and even at the surface. Such soils are designated as carbonate soils.

There is not very much data on the chemical composition of the brown and chestnut soils, but in general it is known that these soils—especially the chestnut-brown—are fairly well supplied with nitrogen, potash, and even phosphoric acid.

Chernozem.—No soil zone has been studied and described by the Russian pedologists more than that of the chernozem. From the days of the famous Russian scholar and scientist Lomonosov, back in the middle of the 18th century, down to our day, the subject of the origin, nature, and properties of chernozem has been investigated time and again. On the basis of his researches on Russian chernozem, Dokuchaev constructed and formulated the modern views of soil science. It has been very well said by the academician Vernadskii that the chernozem has played as important a part in the development of soil science as the frog in physiology or calcite in mineralogy.

Morphologically, chernozem is distinctive because of its dark, almost black, color, which gradually fades with depth. Horizon A, usually quite deep—from 30 to 100 and more cm—blends into horizon B and is therefore divided into two or more sub-horizons. Color alone, however, would not distinguish a chernozem. The clearly expressed granular structure of the soil in the A horizon is one of the primary distinctions between chernozem and any other black soil. With depth the granular structure gives way to a nutty structure. The granular structure of chernozem is due to its saturation with Ca and Mg, as pointed out by Gedroiz (9, 10). This again is one of the primary characteristics of chernozem. Because of that no chernozem can develop on parent material free from calcium. Tanfiliev (38) pointed out this fact in his studies on the geographic distribution of soils.

Lime conditions in the B horizon known as "beloglazki" (white eye spots) and pseudomycellial branching of lime in the lower part of A, or sometimes not very far from the surface, depending on the subtype of chernozem, mark another distinguishing characteristic of the chernozem profile. In the B horizon of a normal chernozem the amount of lime according to Glinka (14, p. 367) is around 16 to 17% and this horizon is designated as the carbonate accumulative horizon.

In typical chernozems there is practically no movement or translocation of the sesquioxides or their silicates and the horizon of illuviation has no excess of these when compared with the other horizons. The low dispersion coefficient of the humus is responsible for this.

Another characteristic feature of the chernozem, although not exclusive for this zone, is the presence of crotovinas, i. e., filled in tracks, passages, and nests of burrowing animals. In some places the work of the rodents is so intense that the distribution of the horizons in the profile cannot be recognized. In a profile cut the crotovinas appear as round, oval, or irregular shaped spots, depending on the angle at which the profile cut transverses the nest or passageway of the rodent. Usually these spots, when located in the brown B horizon, are black, whereas those located in the A horizon are brown. This is due to the shifting of the soil material by the rodents from below to the surface and conversely.

Dokuchaev linked the crotovinas with the processes of soil formation. He considered them primarily as a phenomenon which is connected with the steppe. The subject has been reviewed and investigated by Sukachev (36) and Pankov (23).

Climatogenically, the chernozem belt in Russia lies in a region with an average rainfall of about 500 mm—between 400 and 550 mm—and a mean annual temperature of a little over 5°C—between 3 and 7.5°C. A characteristic feature of the precipitation in the chernozem zone is the seasonal distribution. Most of the rain comes during the summer months and frequently in the form of downpours. With the relatively high summer temperature (18 to 20.5° C) and low humidity, the evaporation is high. Within the chernozem zone the variations in climate produced variations in the soil and we have the following isohumus belts established by Dokuchaev: (a) With 10 to 13% humus, (b) with 7 to 10%, and (c) with 4 to 7%. In the central-eastern part of the chernozem zone lies a strip of soil with more than 13% humus. These belts run parallel with the chernozem zone in general, which runs in the direction of NE to SW.

Whenever a typical chernozem profile is examined the following may be noted:

0–3 cm: A_0—layer, consisting of the grass plant cover with some mineral substances in the entangled mass of small roots. It blends in with the deep A humus horizon.

3–50 cm: A_1—dark colored, granular structure, mellow constitution with a network of small roots.

50–110 cm: A_2—lighter in color than A_1, with dark tongue-like projections, granular-nutty structure, lumpy towards the bottom of the horizon, with some cracks, and more compact.

110–150 cm: B—greyish color, with white spots—lime concretions—poor structure, slightly cracked, and porous.

150—cm: C—parent material, usually loess, light grey colored loam, containing carbonates.

Variations from black to chocolate in color of the soils in the chernozem zone, in structure from laminated lumpy to large grain, in depth of A horizon from 50 to 100 and more cm, in point of effervescence in the profile from a depth of 20 to 120 cm, all produced a natural division of the chernozem zone into the following subtypes: (a) Southern chernozem, chocolate color, depth of 50 to 60 cm, laminated lumpy structure, effervesces at 20 cm and at times even at the surface. This subtype approaches the habitus and constitution of the chestnut zone. (b) Ordinary chernozem, black with some lighter shades, lumpy-granular structure, depth of A horizon 80 cm, effervesces at 60 cm. (c) Deep chernozem, intensely dark color, granular, depth of A 115 cm, effervesces at 80 cm. (d) Degraded chernozem, dark grey with a brownish tinge, lumpy-granular, with some silt, depth of A horizon 100 cm, effervesces at 120 cm. (e) Priazov subtype (found in the region of the Azov sea), dark-grey with various tinges, large grain structure, depth of A 100 cm and more, effervesces at various depths. We also have chernozem-like soils which frequently have no carbonate accumulation zone. Glinka (14) cites examples of such soils.

Forest steppe and podzol[6] zone.—Because of the parallelism in the processes of soil formation in the forest-steppe and in the true podzol region, the two may be considered jointly, as suggested by Glinka (14, p. 464). Morphologically, the true podzols stand out by themselves, but chemically all the soils in the temperate, cool, semi-humid and humid regions show evidence of the podzolization process. Although podzols are identified primarily with the forests of the region, especially with the coniferous forests, still they are found under other forms of vegetation in the climatic belt of this zone. Thus we have (a) meadow podzol soils, (b) peat-podzol soils, and (c) podzol-gley soils.

One of the outstanding profile characters of a podzol soil is the clear-cut differentiation of the horizons of eluviation and illuviation. They stand out sharply in the profile, especially the bleached greyish to white horizon A_2, and this is, perhaps, the reason why this zone has

[6]Podzol is a Russian word derived from the two words "pod" (under) and "zola" (ash). It contains the Russian letter "z" which is pronounced as the letter "z" in "zoology," "zone," etc. In an English transliteration podzol should therefore be spelled with a "z." The erroneous "s" crept in from the German language in which the letter "s" has the sound of "z."

been studied much more than any other zone, save the chernozem. Dokuchaev's first steps in the field of pedology were made on the podzols of the Smolensk district, and Sibirtzev separated out the podzol soils as a zonal type.

According to Glinka (14, p. 464), the climatic conditions of the podzol zone, when a wide range of meteorological data is averaged, are an average yearly rainfall between 500 and 570 mm, with a mean annual temperature of 3.66°C. The data given are for European Russia and adjoining border states. The general morphological habitus of a true podzol profile on a loam parent material is as follows:

A_0: 2–3 cm or more thick (in peat-podzol soils, near Detskoe Selo in the Lisino forests the members of the Second Soil Science Congress had a chance to see an A_0 peat layer 50 to 60 cm deep), consisting primarily of undecomposed or partly decomposed plant residues—grass, leaves, twigs, moss, etc.

A_1: 14 cm (the depth depends primarily on the texture of the parent material), impregnated with some humus material, light grey with a straw-colored tinge, powdery, silty, loose structure, with fine porosity.

A_2: 14 cm, the true podzolized horizon, bleached to a light greyish white color, powdery, loose structure which changes to a laminated structure at the bottom. Sometime granules or concretions of ortstein formation may be noted at the bottom.

B_1: 40 cm, the horizon of illuviation, brownish color with the light tongue-like projections of A_2 in it and veins of a dark humus penetrating it. At the surface the structure is laminated, becoming nutty at the bottom of this horizon. It is of a compact constitution.

B_2: 40 cm, similar to horizon B_1; compact, with some grey podzolized material on the structural units, which are otherwise brownish in color. Fe and Mn concretions might be found and less humus than in B_1.

C: parent material slightly changed at the surface by the soil-forming processes.

In sandy parent material the profile of a podzol is usually deeper than on a heavier parent material especially for horizons A_1 and A_2.

Within the zone of podzolization, under conditions of deciduous forest, the "grey-forest" soils develop, which differ from the true podzols in their morphological characters. In a way the grey-forest soils may be considered as a transition type between the chernozem and the true podzols.

Zakharov (44, p. 334) describes a typical grey-forest soil as follows:

A_0: 0–5 cm, forest litter consisting of dead, semi-decomposed leaves, twigs, fruit of trees, etc.

A_1: 20 cm, grey, slightly laminated, lumpy structure, slightly compacted, with a lot of roots intermingled with the mineral parts.

A_2: 20 cm, grey with a tinge of brown, nutty structure with a pepper and salt effect of silica on the surface of the structural units

(similar silica coating is frequently encountered in the so-called degraded chernozem), is more loose than A_1.

B_1: 45 cm, dark brown with black spots, large nutty structure, prismatic at the bottom, more compact and sticky; horizon of illuviation where the sesquioxides are washed in.

B_2: 50 cm, straw-colored with a brownish tinge, poorly expressed prismatic-like structure with dark brown and greyish tongue projections from B_1, slightly cracked. Carbonates are present and sometimes even in the form of white veins.

C: Parent material.

The striking characteristic of the grey forest soil profile is the grey color of the A horizon which turns into brownish with depth. Chemically, both the true podzols and the forest grey soils differ but little. Both are acid with an increase in the intensity of acidity from the surface down to horizon B where the acidity decreases. The base exchange capacity is lowest in A_2, the latter being the poorest in colloids. With depth the capacity for base exchange increases because of the illuviation of the colloids.

In general it is true that the B horizon of the forest-steppe and podzol zone accumulates bases and sesquioxides. There are some podzols, however, where the sesquioxides have not accumulated. This is especially noticeable in some of the podzol-gley soils, where the activity of the ground waters determines the sesquioxide regime in the layers which are subjected to the action of the ground waters. Reducing and oxidizing reactions interchange, due to the receding and rising water table. The former is conducive to the carrying away of the iron in soluble reduced form, the latter tends to precipitate the iron, age the gels, and prevent its escape. The balance between these two reactions seems to play a part in the sesquioxide balance in the horizon of illuviation. The amount of humus which serves as a protective agent in the downward movement of sesquioxides is another factor to be mentioned in this connection.

Closely related to the forest-grey soils are the rendzina which develop, in the early stages, in an alkaline medium just like the chernozem, gradually lose the bases, and mature in an acid medium, just like podzols. These soils do not belong to the climatogenic group since the parent material is the factor responsible for the rendzina formation.

Another type of soils encountered in connection with the deciduous forests is the brown earth, the "Braunerde" of Ramann.

According to Ramann (26, p. 86–88), "the brown earths develop under the influence of a temperate climate which fluctuates greatly; some years are wet and others dry so that the leaching of the soil

is very much greater at some times, very much less at others. The rainfall is not sufficient during the warm season to form seepage water in soils which are covered with vegetation. In warm and dry years slightly arid conditions prevail, so that the effects of the ascent of the ground water are seen. This is mainly evidenced by the soil water being enriched in calcium carbonate, though deposits of calcium carbonate in appreciable quantities are rare or are only found in soils having an abundant water supply as in the loess. Leaching preponderates in most of the brown earths; the soluble salts and the earthy carbonates are washed out, while phosphates and the sesquioxides are retained in the soil....In no other soil formation does the parent rock exercise such a large influence as in the brown earths...The soil has normally a neutral or slightly alkaline reaction; hence readily dispersed humus bodies are not found."

Ramann gives no data on the profile constitution and habitus of the brown earths and he deplores the fact that "there is a surprising lack of investigations of complete soil profiles, which provide an insight into the processes of weathering."

A series of brown earth profiles are described by Glinka (11), but he considers these soils as a variety in the podzol zone, and as a condition for the formation of the "Braunerde" he lays down the prerequisite of carbonates of lime in the parent material.

In another place Glinka (13) states, "all the participants of the excursion (in connection with the soil conference in Hungary: J. S. J.), who happened to study the brown earths in their respective countries have agreed with me that the brown earths examined by us represent one of the varieties of the podzol type of soil formation on carbonate loams." It is to be noted that the brown soils in most cases contain carbonates in the lower horizon.

Glinka (14, p. 343) considers the brown earths as a transition type, "the brown earths of Western Europe represent, so to speak, the last stage of the podzolized type of weathering; they are transitory to the more southern yellow, and red earths." This idea was expressed long before by Bogoslovskii (3, p. 367).

Some brown earths in Crimea have been described by Antipod-Karataev and his collaborators (2). They found no effervescence in the B horizon. Stebut (34) has recently contributed to the problem of brown earths. The entire question of "Braunerde" needs further study before anything definite may be said.

The tundra zone.—In Russian popular language "tundra" implies every kind of muck. It is really the vast treeless plain of the arctic region. Variations in rainfall within the plain mark the differentiation of the tundra into (a) desert tundra, (b) dry tundra, and (c) peat tundra, which, according to Zakharov, (44, p. 351), correspond

pedologically to the arid, semi-arid, and humid types of soils, respectively.

One of the characteristic features of the tundra zone climate is the long winters with the long nights and low temperature. The average low temperature in Western Siberia is — 12 to — 17°C, with the rather low rainfall of 300 to 200 mm and less. The presence of the perpetually frozen layer at some depth below the surface, the depth depending primarily on the latitude, the short summer, and prevailing low temperatures allow water logging of the soil below the surface. Thus, conditions are conducive to swampy formations, a typical feature of the tundra in general.

Among the different varieties of tundra landscape is one known as the bog (hillock). These bogs may have a diameter of 5 to 25 meters, 3 to 5 meters high. They are separated by depressions 5 to 15 meters wide which are filled with water, and the perpetually frozen layer is within 40 cm of the surface. Such a tundra variety has been described by Tanfiliev (37), for eastern Lapland. The prevailing vegetation is lichens and mosses.

In the river valleys, meadows and even some trees are to be found, which of course influence the process of soil formation. This type of vegetation is due to the lowering of the layer of perpetual freezing.

The morphology of the so-called "dry tundra" is given by Sukachev (35) as follows:

0–3 cm: A_0—the humus horizon, greyish brown in places with a small amount of decomposed plant material.

3–6 cm: A_1—yellowish brown, in places greyish brown, ochreous loose loam.

6–16 cm: A_2—dark blue-grey homogeneous viscous loam; when dug out it flows; in a monolithic box it becomes liquid like; there is a sharp line of separation between this and the overlying horizon.

16–19 cm: B_1—brownish yellow loam, similar to A_1 but more compact.

19–50 cm: B_2—compact, dark brownish grey loam; in the lower part of this horizon black spots (humus) and rock fragments are found. At a depth of 79 cm the frozen layer was encountered.

According to Zakharov (44, p. 352), "the soil described resembles morphologically a weakly podzolized soil with indications of swamping."

A chemical analysis of the soil from the various horizons shows practically no translocation of the various chemical constituents. A slight decrease in iron is indicated in the A_2 horizon.

An interesting presentation on the peculiarities of the tundra process of soil formation is given by Grigoriev (15) as follows:

"All agree that tundra soils belong to the marsh type of soil formation. Whether this type differs much from the generally recog-

nized marsh type is a question still unsettled. Without attempting to solve the question, I call attention to several details of the tundra process.

"It is known that the rainfall in the tundra is low; the free play of the winds, which at times blow with great force, make up the evaporation deficit due to the short summers. Consequently the snow cover cannot be deep here. Furthermore, the intensity of evaporation in the spring under the combined forces of the sun and the wind must be quite intense. We might expect large quantities of water from the thawing snow. The major portion of this water runs off and is not available to the soil, which remains frozen. On the other hand a lot of water is being absorbed and transpired by the lichens and mosses, which are capable of doing it while the roots of the more highly organized plants are inactive. Thus the utilization of the vernal waters by the plant cover in the tundra begins relatively early.

"By the time the tundra soil with its low heat conducting moss-lichen cover and thin peat litter layer begins to thaw out most of the thawing waters have run off. Only a small portion of the thawing waters penetrate the soil, thereby influencing the soil forming processes. Coming in contact with the layer of perpetual freezing these waters partly freeze, but at the same time exert a thawing effect on the layer of perpetual freezing. The waters produced by the partial thawing out do not hinder the incoming water from penetrating into that frozen layer, since the thawing out process which involves a change from the solid to the liquid phase produces a decrease in volume, making room for the incoming water. And besides, the frozen layer is not devoid of porosity, which depends on the amount of water present in the soil at the time of freezing. It is natural, however, to find the soils saturated with water during the spring.

"However, this period of saturation does not last long, because the supply of thawing waters is limited, the rainfall in the tundra is low, the evaporation during the nightless period is considerable, and, as mentioned, the mosses and lichens take up a lot of the rain water before it has a chance to reach the soil. Because of the drying out effect of the surface horizons there must sometime be established an upward movement of water. This upward movement might change again to a downward movement after heavy rains."

In the light of Lebedev's (20) work one might expect during the summer a condensation of vapor from the surface at the point of the layer of freezing, since the vapor pressure at the surface during the summer is higher than below.

Grigoriev continues to develop his ideas on the upward and downward movement of water and cites an example where 10 to 25 cm of the surface soil in the tundra is dry while it is overlying a saturated layer. All that has been said points towards the conclusion that the soil-forming processes in the tundra do not take place under conditions of constant saturation as generally believed.

Keeping this in mind one can see how the podzolization process could extend into the forest-tundra belt and even in the belt of the pure tundra.

Grigoriev (15) describes a series of profile cuts in the forest-tundra and in the genuine tundra on loam and on sandy parent material. He compares his findings with those of Dranitzuin (7), Sukachev (35), Tanifiliev (37), and others. On the sandy parent material Grigoriev found deep peat layers—at times more than 60–70 cm.—especially in the depressions where the marshy processes are well expressed. These soils show distinct podzolization of the gley type. On the loams the process of soil formation is feebly expressed.

In the continental dry portions of the arctic region in eastern Siberia one could encounter among the genuine tundra some solonchak formation. These have been studied by Dranitzuin (7) and Skvortzov (33), but not enough to give sufficient data to prove the genuine solonchak process of soil formation.

In summing up the tundra type of soil formation, it is well to remember that it is very intimately connected with the phenomenon of perpetual freezing which is inducive to marsh formation. Since the phenomenon of perpetual freezing is encountered in the extreme northern portion of the forest zone, we find the tundra type in this zone and we thus have besides the genuine tundra also the forest-tundra.

Red soils.—Under the caption of red soils the Russian pedologists take in those which develop in the tropics and sub-tropics. In this climatic zone two groups of red soils are distinguished by Glinka (14, p. 294), *viz.*, those which develop under humid conditions and under arid conditions, respectively. Both groups possess color only in common differing in composition and other properties.

In the desert steppe regions of Australia, Brazil, and Africa extensive areas of red soils are found. They have been mapped by Glinka as a distinct group on the preliminary soil map of the world which was published by Prassolov (25). In their mode of formation and morphology these red soils seem to be analogous to the arid-steppe brown and semi-desert steppe grey soils of southern Russia or Turkestan. Efflorescence of lime and lime concretions at some depth is one important point of similarity between the red soils of the arid tropics and sub-tropics and of the brown and grey soils.

According to Dranitzuin (8), the red soils of the sub-tropics differ from the brown and grey soils of the Turkestan semi-desert in their reddish tint, in all other respects having the same profile features. Similar observations were made by Glinka (14, p. 294) on some

Spanish soils. In general, however, very little is known about this group of soils and the nature of the reddish tint, which is a laterite characteristic, is not understood.

The other group of red soils, known as laterites and laterite-like soils, develops under humid conditions in the tropics and sub-tropics. These have been studied but little by the Russian pedologists except for the laterite-like red soils, the so-called "terra rossa" in the Caucasus. Most of the discussions on this type of soil formation are based on the observations and investigations of Western European scientists, including Buchanan (4), who introduced the term "laterite" more than a century ago; Richthofen (27); Wohltmann (42); Meyer (21); Passarge (24); and a number of others. A summary and an analysis of the investigations mentioned are given by Glinka (14, pp. 294–311).

Since this paper deals primarily with the Russian point of view on the profile constitution and since no data are presented by the Russian pedologists, it was felt that a discussion of the laterites would not be appropriate at this point. It will be interesting, however, to mention briefly the theoretical views of just two leading men in the field of soil science, *viz.*, Glinka and Gedroiz.

According to Glinka (12), the lateritic type of soil formation takes place in a weakly alkaline medium with an intense decomposition of the aluminum and iron silicates. It is the coagulation of the gels in this medium which is responsible for the accumulation of iron and aluminum in the upper horizons.

Gedroiz (9, 10) considers the lateritic type of soil formation analogous to that of the podzol. Both have a low saturation coefficient. In the lateritic type the intense decomposition of the organic materials is favorable for a rapid displacement of the alkaline earth cations which coagulate the Fe and Al from the rapidly decomposing silicates. The speedy mineralization of the organic matter supplies again mineral cations which serve as coagulators of the iron and aluminium.

The "terra rossa" (red earth) has been studied by the Russian investigators ever since Dokuchaev described the red soils of Chakva near Batum in the Caucasus,[7] still the genesis of this type of soil is not as yet well understood. A typical profile of red earth in Western Georgia (Caucasus) is described by Zakharov (44, p. 313) as follows:

[7]On the recent excursion of the Second International Congress of Soil Science the writer, together with a group of members of the excursion, visited the same profile cut which was studied by Dokuchaev, Glinka, and other Russian pedologists.

0–20 cm: A_1—brownish grey, changing into a brown shade at the bottom, powdery structure which changes at the bottom into a lumpy-granular structure, loose constitution, loam.

20–40 cm: A_2—brownish orange dull coloration, lumpy, feebly expressed nutty structure, more compact and sticky when wet, loam.

40–75 cm: B—illuvial horizon, bright homogeneous orange coloration, not clearly expressed large lumpy structure with thin cracks, quite sticky and compact, especially in the upper part, at times with dark and brown veins, loams.

75—cm: C—brightly colored with the predominance of orange; here and there spots of bright red, white, black, and greenish brown are found; having no structure, loose, mellow loam, going down to a depth of 150 to 250 cm and representing the upper portion of the belt of weathering of andesitic tuff.

Morphologically, according to Zakharov, the soil described resembles the forest-grey soils, but it lacks the silica pepper and salt coating effect. Chemically, the red earths are distinguished by the high amount of organic matter in the A horizon. This is in contradiction with the lateritic process of soil formation where the mineralization process of the organic matter is complete and no accumulation of organic matter takes place. There is no lime carbonate in the red earths. They also contain a high amount of chemically combined water which indicates the presence of hydrogels. They are high in sesquioxides which are uniformly distributed in the profile. On the other hand, there seems to be an impoverishment in silica. They are unsaturated and low in base exchange capacity, something which makes them resemble the podzolized soils. This view is shared by Gedroiz (9, 10) and Vilenskii (40).

Alkali soils.—Thus far the zonal distribution of climatogenic soils has been considered. There is, however, one intrazonal soil which deserves attention, namely the alkali soils.[8] They are hydrogenic inasmuch as the moisture regime is one of the dominating factors in the soil-forming processes.

Two kinds of alkali soils are recognized, *viz.*, (a) The "solonchak," without structure or feebly developed structure; and (b) the "solonetz," with a definite structure. Both of these types (not in the sense of zonal types) are secondary soils which develop on other zonal types because of a salinizing process of soil formation.[9] The solonchak is the first stage in the development and the solonetz the second stage. These two stages were differentiated on the basis

[8]Under "alkali soils" the author understands both "solonchak" and "solonetz."

[9]Vilenskii (39) recognizes the possibility of primary salinization also. In that case there is very little humus in the soil, neither has it any traces of a structure. In the secondary soils there is an appreciable amount of humus and remnants of a structure from the original soil.

of the anions in the salinizing process, *viz.*, chlorides and sulfates and carbonates. But Gedroiz (10) in his classical researches on the nature of the cation exchange in the various processes of soil formation revolutionized the ideas on the origin of the two stages in the salinizing process.

According to Gedroiz (10, p. 79), salinized soils with the salts of sodium, calcium, and magnesium might be sodium solonchak, magnesium solonchak, or calcium solonchak. There might also be a mixed solonchak. Depending on the cation of the salt present the complex capable of base exchange will become saturated with the respective cations. It is the cations that determine the nature of the alkali soil.

Whenever a desalinizing process takes place, such higher precipitation or a lowering of the water table in depressions, the solonchak does not revert back to its original normal type but attains the properties of the solonetz, i. e., the salt is washed out completely or partly and the base exchange complex remains saturated with one or two cations, usually with sodium predominating. As a result, the dispersion of the colloids increases and they are therefore subject to a more rapid decomposition. Silica is then set free and the sesquioxides, together with some humus, move downward and impart to the B horizon its characteristic somewhat compact constitution.

Whereas the solonchak is a product of the contact of the ground waters with the surface by capillary forces, the solonetz is the product of the downward movement of moisture with a deep-lying water table which has no contact with the surface horizon. Whenever the water table on a solonetz establishes contact with the surface,[10] a secondary salinization takes place and secondary or regraded solonchak is produced, as shown by Vilenskii (39, p. 10). Similarly, secondary or regraded solonetz is possible

In the early stages of its development solonchak is wet, but we might also have a dry solonchak just at the time when the water table begins to recede. The dry solonchak under the conditions mentioned might be looked upon as a transition stage from solonchak to solonetz. According to Visotzkii (41) there might be a deep solonchak, e. g., where the ground waters do not reach the surface but evaporate through the soil at a certain depth. This again might be a transition stage from solonchak to solonetz.

A typical profile of solonetz is given by Zakharov (44, p. 368) as follows:

0–5 cm A_1 horizon—light color, no structure, loose, fine porosity.

[10]This is sometimes made possible by the imperviousness of the solonetz to the rain water. In this case a temporary high water table is established.

5–10 cm: A_2 horizon—lighter than A_1, foliated structure, slightly more compact.

10–18 cm: B_1 horizon—dark brown chestnut very compact, with cracks, columnar, the mass of which falls apart into many angular units; the columns are rounded at the top.

18–30–35 cm: B_2 horizon—slightly lighter in color than B_1, nutty-granular structure, fairly well stratified.

35–– cm: C horizon––loess-like material with veins of the soluble salts and carbonates.

The soluble salt content in the upper horizons of a solonetz is not great, at any rate not much more than in any neighboring normal soil. As an intrazonal type the alkali soils are distributed among the zonal types of the dry regions all over the world. They occupy, according to Zakharov (44, p. 371), tremendous areas, comprising 24% of the area of the U. S S. R. The other hydrogenic soils to be mentioned are (a) marsh soils, (b) peat-marsh, (c) meadow-marsh, and (d) meadow soils.

GENERAL STATEMENT

A full discussion of Russian studies on soil profiles has not been attempted in the review given here, as that would require a monograph which should cover the widely scattered Russian literature for the last 50 years. Undoubtedly it would be an undertaking worth our while, but ambition of such a high order has not been entertained even by the Russians themselves.

The discussion purports to touch the high spots and to outline the broad features of the Russian system of soil science so far as the soil profile is concerned. The subject might be approached from the angle of the chemist, the physicist, the biologist, the survey man, the agronomist, the geo-botanist, or any number of other scientific disciples. Anyone will find the soil profile a fruitful field of study. The agronomic phase was not covered by the Russian literature of the earlier period, neither were the biological reactions and activities prominent in the soil profile studied by the biologist. In recent years both of these subjects have been attacked and some excellent work has been done, but the possibilities are still great and are awaiting the searching mind.

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IS THE SOIL TYPE HOMOGENEOUS WITH RESPECT TO ITS FERTILIZER NEEDS?[1]

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It has frequently been assumed that the results of a fertilizer test on a given soil type will, if accurate for the field on which the test was made, be applicable to any soil representing that type. This assumption does not appear to have been subjected to much experimental confirmation. There are few instances in which fertilizer experiments have been duplicated on fields located at some distance apart on the same soil type. Even tests in greenhouse pots designed to accomplish the same end have not come to the attention of the writer. Experiments are recorded in which the results of field tests have been compared with similar tests in greenhouse pots, or wire baskets, but soil for the latter has been taken from a check plat or land adjacent to the former.

If fertilizer experiments on a given soil type are to serve as the criterion for recommendations of fertilizer treatment on that type it would seem to be desirable to ascertain to what degree of precision such recommendations can be made. It has never been claimed by the persons who developed the classification and correlation of soils in this country that soil type has any relation to fertilizer response. The classification was not designed with that in view. If it should turn out to be the case, it would be accidental, at least so far as the intentions of the originators are concerned.

At an earlier time in the history of the experiment stations results of fertilizer tests were regarded as of more or less general application. With the adoption of the present system of soil classification it became the custom for experiment stations to establish fertilizer tests on outlying fields located on certain soil types. These local fields have the advantage of subjecting the tests to a number of local conditions which involve, among others, drainage, altitude, topography, temperature, and length of growing period. Some specific conditions of this kind may always be associated with certain types. For instance, good or poor drainage may be one of the conditions which determines the type. Again certain soil types are found mainly at high altitudes, others on bottom land, while others occur predominately on hillsides. To the extent that these conditions affect the action of fertilizers and are characteristic of the regions in which a given soil type

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habitually occurs, the results of a fertilizer trial on that particular type are obviously more applicable to that type than is one conducted on another type.

OBJECT OF THE EXPERIMENT

The experiment here described was designed to furnish some data concerning the uniformity of the response of a given soil type to fertilizers. That being the case it was necessary to conduct the same kind of fertilizer tests on two or more samples of the same type, and to use several types in this way. Also, it was desirable to conduct all of the tests under conditions as similar as it was possible to make them. If, under these circumstances, the same treatments produced approximately the same effects on each of the samples of a given soil type, the fact would support the idea that a given fertilizer treatment could be recommended for the type as a whole, provided other conditions do not interfere. On the other hand, failure to obtain reasonable uniformity would argue that the soil type, aside from its accompanying external conditions, is not entirely reliable for use as a guide in making recommendations for fertilizer treatments.

SOILS AND APPARATUS USED

Four types of soil were selected for the experiment, *viz.*, Ontario loam, Volusia silt loam, Dutchess silt loam, and Vergennes clay. In the years intervening between these selections and the present, there has been some revision of the designations, with the result that one of the Ontario loam samples is now classified as Honeoye silt loam, and of the four Volusia silt loam samples two are now called Volusia stony silt loam and two Volusia silty clay loam. These revisions do not affect the plan of the experiment seriously since the Ontario and Honeoye series are closely related, and the change in the Volusia series involves only a minor textural difference. It is natural that changes should be made as the system of soil classification develops, but, unless a very serious mistake has been made in the original survey, one may expect these revisions to be of minor importance, as they are in these cases.

Of these soils similar tests were conducted on two or more samples of each type, the samples having been taken from widely separated localities. Each sample consisted of between 9 and 10 tons of soil, placed in galvanized iron rims painted inside and out, and imbedded in the ground except for 2 inches at the top. The rims were 40 inches long and 24 inches in diameter. All of them had tile drains running

underneath. In the bottom was placed a shallow layer of clear sand and above that the soil to be tested, the latter being arranged in three layers of 1 foot each in the order in which they occurred in the field. Stones larger than a hen's egg were removed before placing the soil in the rims.

There were four samples of the Ontario and Honeoye series, four of the Volusia, two of the Dutchess, and two of the Vergennes. The samples were removed from the field in three 1-foot layers, packed in bags holding about 100 pounds each, and shipped to the Experiment Station either by rail or by motor truck. Care was taken to secure soil that had received little or no lime or no commercial fertilizer. A somewhat detailed description of the samples is given in Cornell University Agricultural Experiment Station Bulletin No. 520 and will not be repeated here.

APPLICATIONS OF LIME

It required several years to collect these samples and some remained for some time in the rims before being limed and fertilized, although they were cropped each year. A determination of the lime requirement of each sample was made by the Veitch method and ground limestone was applied in an amount to meet the requirement of 3,000,000 pounds of surface soil per acre. The lime requirements expressed in CaO were as follows:

Soil type	Location	Pounds of CaO per acre
Ontario loam	Oneida County	450
Ontario loam	Monroe County	None
Ontario loam	Cato, Cayuga County	None
Honeoye loam	Sherwood, Cayuga County	None
Volusia stony silt loam	Turkey Hill, Tompkins County	8,700
Volusia stony silt loam	Cayuta, Tompkins County	5,100
Volusia silty clay loam	Cortland County	6,900
Volusia silty clay loam	Alleghany County	9,000
Dutchess silt loam	Dutchess County	5,850
Dutchess silt loam	Orange County	6,300
Vergennes clay	Washington County	2,850
Vergennes clay	Jefferson County	2,550

These treatments were given in 1916–17 and were repeated in 1920, except on the Cortland and Alleghany County soils, which were limed for the first time in that year.

CHEMICAL ANALYSES OF THE SOILS

Samples of the soils used for the analyses were taken by making 20 borings in the field from which the samples were taken for the fertilizer tests, or from nearby land. The borings were drawn from three

depths, *viz.*, 0–8 inches, 8–24 inches, and 24–36 inches. Bulk analyses were made of these samples (1),[3] and the results are given in Table 1.

TABLE 1.—*Chemical composition of soil types used in the experiment.*

Location	Sample depth, inches	Constituents of soil in % of dry soil: N	P	S	K	Ca	Mg
	Ontario Loam						
Oneida County	0–8	0.404	0.119	0.057	1.98	0.84	0.73
	8–24	0.097	0.079	0.038	2.21	1.77	0.93
	24–36	0.127	0.082	0.031	2.10	0.66	0.84
Monroe County	0–8	0.248	0.072	0.135	1.72	0.93	0.54
	8–24	0.059	0.054	0.115	2.00	1.06	0.75
	24–36	0.039	0.054	0.107	1.92	3.14	1.61
Sherwood, Cayuga County	0–8	0.164	0.041	0.057	1.60	0.71	0.51
	8–24	0.076	0.058	0.068	1.47	4.84	1.53
	24–36	0.073	0.052	0.045	1.72	4.55	1.42
Cato, Cayuga County	0–8	0.214	0.033	0.094	1.49	0.84	0.42
	8–24	0.079	0.058	0.038	1.62	0.81	0.49
	24–36	0.047	0.042	0.040	1.63	3.36	1.04
	Volusia Stony Silt Loam						
Turkey Hill, Tompkins County	0–8	0.215	0.075	0.068	1.71	0.37	0.56
	8–24	0.206	0.044	0.044	1.93	0.31	0.60
	24–36	0.156	0.046	0.044	2.10	0.34	0.70
Cayuta, Tompkins County	0–8	0.248	0.079	0.098	1.69	0.35	0.49
	8–24	0.170	0.033	0.085	2.11	0.22	0.71
	24–36	0.174	0.028	0.050	2.40	0.24	0.71
	Volusia Silty Clay Loam						
Cortland County	0–8	0.281	0.047	0.080	2.06	0.16	0.46
	8–24	0.126	0.038	0.086	2.27	0.11	0.65
	24–36	0.071	0.035	0.065	2.12	0.14	0.67
Alleghany County	0–8	0.257	0.057	0.085	2.19	0.36	0.57
	8–24	0.094	0.031	0.065	2.88	0.23	0.75
	24–36	0.074	0.035	0.105	2.74	0.25	0.78
	Dutchess Silt Loam						
Dutchess County	0–8	0.168	0.059	0.027	1.56	0.24	0.66
	8–24	0.073	0.047	0.015	2.03	0.17	0.83
	24–36	0.063	0.045	0.018	2.38	0.36	0.97
Orange County	0–8	0.215	0.055	0.104	1.07	0.18	0.44
	8–24	0.077	0.028	0.087	1.33	0.18	0.54
	24–36	0.055	0.033	0.057	1.55	0.26	0.58
	Vergennes Clay						
Washington County	0–8	0.368	0.103	0.078	2.60	0.52	1.09
	8–24	0.123	0.060	0.033	3.11	1.31	1.36
	24–36	0.093	0.068	0.121	3.19	3.57	1.63
Jefferson County	0–8	0.186	0.070	0.051	2.61	0.55	0.89
	8–24	0.072	0.065	0.052	3.19	0.76	1.78
	24–36	0.051	0.086	0.058	3.30	2.17	2.25

[3]Reference by number is to "Literature Cited," p. 71.

The statement of the analyses shows great variations within the types. Such differences as 0.164 to 0.404 in nitrogen and 0.033 and 0.119 in phosphorus which occur in Ontario loam and 0.186 to 0.368 in nitrogen and 0.070 to 0.103 in phosphorus, which occur in Vergennes clay do not suggest uniformity in the chemical composition of soil types. Nor does there appear to be any correlation between the productivity of a soil type and its chemical composition, unless it is in its content of calcium, as has been shown by Bizzell (1) to be a characteristic of these and other New York soils.

In Table 2 is shown the average yields of nine crops on the unlimed and unfertilized soils in the rims and the calcium content of the soil for which the crop yield is given. The relation between the calcium content of a soil type and the crop yield is well brought out by this table.

TABLE 2.- *Average yields of all crops on unlimed and unfertilized soil, together with the calcium content of the respective soils.*

Location	Crop yield, grams	Calcium in % of dry soil		
		0–8 in.	8–24 in.	24–36 in.
Ontario and Honeoye				
Oneida County	128	0.84	1.77	0.66
Monroe County	108	0.93	1.06	3.14
Cato, Cayuga County	124	0.84	0.81	3.36
Sherwood, Cayuga County	145	0.71	4.84	4.55
Volusia				
Turkey Hill, Tompkins County	14	0.37	0.31	0.34
Cayuta, Tompkins County	62	0.35	0.22	0.24
Cortland County	55	0.16	0.11	0.14
Alleghany County	82	0.36	0.23	0.25
Dutchess				
Dutchess County	52	0.24	0.17	0.36
Orange County	22	0.18	0.18	0.26
Vergennes				
Washington County	116	0.52	1.31	3.57
Jefferson County	146	0.55	0.76	2.17

It will be noted that calcium is uniformly low in those types that are shown in Table 2 to be relatively unproductive, and high in the good soils. Furthermore, there seems to be no relation between the chemical composition of the samples and their response to fertilizers after they have been limed, as may be seen by reference to Tables 1 and 6.

FERTILIZER APPLICATIONS

Each sample of soil was given several different fertilizer treatments. Complete fertilizers were applied each year to certain rims,

except those years in which clover was grown when no nitrogen was applied. Nitrogen was in the form of nitrate of soda, phosphorus in superphosphate (16% P_2O_5), and potassium in the form of muriate of potash. On certain rims a single fertilizer constituent was omitted. All fertilizers were applied annually. The various treatments will sometimes be referred to in the text by the following abbreviations:

NPL = Nitrate of soda, superphosphate, and lime.
PKL = Superphosphate, muriate of potash, and lime.
NKL = Nitrate of soda, muriate of potash, and lime.
NPKL = Nitrate of soda, superphosphate, muriate of potash, and lime.
No fert. L = No fertilizer, but lime as usual.
No fert. no L = No fertilizer and no lime.

The rates at which applications of fertilizer were made varied with the different crops. They are given herewith.

	Fertilizer in grams per rim		
	Nitrate of soda	Superphosphate	Muriate of potash
Fodder corn	13.1	13.1	3.3
Timothy	19.6	13.1	3.3
Barley	6.5	13.1	3.3
Clover	None	13.1	3.3

PLANTS GROWN IN THE EXPERIMENT

The experiments did not begin on all of the samples at the same time since it required several years to assemble these large quantities of soil. During the period intervening between filling the rims and beginning the experiment, crops were grown each year. Experiments on one-half the number of samples began two years before those on the remaining samples. During those years in which all of the samples were being tested, the crops were the same throughout. The cropping was as follows:

Year	Two samples of Ontario, two of Volusia, two of Dutchess	Year	Two samples of Ontario or Honeoye, two of Volusia, two of Vergennes
1918	Barley	1920	Barley
1919	Crop a failure	1921	Red clover, 2 cuttings
1920	Barley	1922	Fodder corn
1921	Red clover, 2 cuttings	1923	Timothy
1922	Fodder corn	1924	Barley
1923	Timothy	1925	Red clover, 2 cuttings
1924	Barley	1926	Fodder corn
1925	Red clover, 2 cuttings	1927	Timothy
1926	Fodder corn	1928	Barley
1927	Timothy	1929	Red clover, 2 cuttings

Red clover was sown with the barley in 1918 with the expectation that it would furnish a crop in 1919. However, it partly winter-killed and was too irregular in stand to serve as a satisfactory crop for the experiment. It is not included in the results. After this experience red clover was always sown in the spring on the rims and no nurse crop was used. Sown in this way the plants grew rapidly and uniformly and two cuttings were always secured in the one season.

Timothy also was seeded without a nurse crop, but was sown in the autumn. It did not suffer from winterkilling.

Barley was planted thickly enough to permit thinning to 80 plants in each rim. Fodder corn was used in order to get as large a number of corn plants as possible in a rim. It was thinned out to 10 plants.

DIFFERENCES WITHIN SOIL TYPES IN THEIR RESPONSE TO SINGLE PLANT NUTRIENTS

There were four samples of Ontario and Honeoye and the same number of Volusia soils. Of Dutchess and Vergennes soils there were two samples each. A study of the response of the individual samples to each of the several plant nutrients should give some indication of the uniformity within the type to its fertilizer needs. Table 3 gives the relative yields of the total of all crops grown on each soil sample in which the total yield from the treatments in which a given element is omitted is taken as 100 and the total yields from the complete fertilizer treatment is calculated on the same basis. For example, the total yields of the nine crops grown on the NPL treatment are expressed as 100 and the total yields on the NPKL treatment is divided by the former and multiplied by 100 to show the effect of the application of potassium on the crop yield.

Considering first the response to phosphorus, it will be noticed in Table 3 that there are some rather wide variations between the samples. Of the four samples of Ontario and Honeoye there is one that differs quite widely from the others. The same is true of the samples of Volusia. The widest variations are in the Dutchess and the Vergennes samples.

The responses to potassium are more uniform. With the exception of Volusia, the test for any one sample might be taken to show rather accurately the crop response of any other sample of the same type. However, the results of the test of Volusia samples make any such general conclusion impossible.

Applications of nitrogen produced greater increases in crop growth than did those of other plant nutrients. There can be no doubt of the need of any of the soils for nitrogen. It would be only a question of how much to apply In studying the uniformity of response of

TABLE 3.—*Relative yields for each soil sample from treatments with three nutrients based on yields with one omitted taken as 100.*

Location	Phosphorus		Potassium		Nitrogen	
	Without	With	Without	With	Without	With
Ontario and Honeoye						
Oneida Co	100	147	100	109	100	172
Monroe Co	100	159	100	108	100	146
Cato, Cayuga Co	100	130	100	109	100	147
Sherwood, Cayuga Co	100	155	100	106	100	163
Volusia						
Turkey Hill, Tompkins Co.	100	104	100	122	100	134
Cayuta, Tompkins Co	100	130	100	106	100	167
Cortland Co	100	105	100	112	100	124
Alleghany Co	100	106	100	97	100	120
Dutchess						
Dutchess Co	100	133	100	136	100	149
Orange Co	100	109	100	130	100	150
Vergennes						
Washington Co	100	138	100	105	100	152
Jefferson Co	100	109	100	100	100	147

samples within a soil type, we may again use the yields from treatments NPL and NKL. The significance of these has been explained previously. The relative yields are stated in Table 4.

TABLE 4.—*Relative yields for each soil sample from treatments NPL and NKL.*

Location	NPL	NKL
Ontario and Honeoye		
Oneida Co	100	74
Monroe Co	100	68
Cato, Cayuga Co	100	83
Sherwood, Cayuga Co	100	68
Volusia		
Turkey Hill, Tompkins Co	100	117
Cayuta, Tompkins Co	100	81
Cortland Co	100	107
Alleghany Co	100	91
Dutchess		
Dutchess Co	100	102
Orange Co	100	120
Vergennes		
Washington Co	100	76
Jefferson Co	100	94

The relative effects of phosphorus and potassium, as indicated by Table 4, are, in a general way, much the same as those suggested by Table 3. The variations within Ontario loam are moderate, but in Volusia they are large. For instance in Volusia samples there are two cases in which potassium has produced larger crop yields than has phosphorus and there are two instances in which the op-

posite result has occurred. In Dutchess silt loam potassium was more effective than phosphorus, but the difference in response between the two samples was rather large, and in Vergennes it was still greater.

DIFFERENCES WITHIN SOIL TYPES IN THEIR RESPONSE TO COMPLETE FERTILIZER

Since one of the treatments called for lime only and another for lime and complete fertilizer, the effect of adding a complete fertilizer to a limed soil may be determined for each soil sample. Table 5 gives the relative yields on the unfertilized and fertilized soil after liming.

TABLE 5.—*Relative yields of crops on limed soil when not fertilized and when treated with complete fertilizer.*

Type	L	NPKL
Ontario and Honeoye		
Oneida County	100	187
Monroe County	100	234
Cato, Cayuga County	100	197
Sherwood, Cayuga County	100	177
Volusia		
Turkey Hill, Tompkins County	100	213
Cayuta, Tompkins County	100	182
Cortland County	100	146
Alleghany County	100	145
Dutchess		
Dutchess County	100	217
Orange County	100	190
Vergennes		
Washington County	100	170
Jefferson County	100	168

Here again there are wide variations within the same soil type. The only type within which the effect of fertilization is fairly constant is Vergennes clay.

Another possible result of complete fertilization to be considered is whether the treatment brought the yields on a given soil type to an approximate level. If this were the case the effect of the treatment might, in a sense, be considered to be uniform. The available data bearing on this are contained in Table 6.

While Table 6 shows the yields from the four samples of Ontario and two of Vergennes treated with complete fertilizer to be remarkably uniform, the same cannot be said for Volusia and Dutchess. The Volusia gave widely divergent yields and the Dutchess rather variable ones. It will be noticed that those types the yields of whose unfertilized samples are most irregular, are the ones whose fertilized samples have the greatest variations.

TABLE 6.—*Average yields of nine crops on limed soil when not fertilized and also when treated with complete fertilizer.*

Type	L	NPKL
Ontario and Honeoye		
Oneida County	125*	230
Monroe County	103	241
Cato, Cayuga County	114	238
Sherwood, Cayuga County	130	238
Volusia		
Turkey Hill, Tompkins County	98	209
Cayuta, Tompkins County	138	239
Cortland County	175	257
Alleghany County	183	266
Dutchess		
Dutchess County	110	239
Orange County	115	218
Vergennes		
Washington County	139	247
Jefferson County	150	250

*Figures are for grams per rim.

DIFFERENCES BETWEEN SOIL TYPES, WHEN NOT LIMED, IN THEIR RESPONSE TO LIME AND COMPLETE FERTILIZER

Still more variable than the effect of the complete fertilizer alone was that of lime and complete fertilizer combined. In Table 7 are recorded the relative yields of the nine crops on soil which received neither lime nor fertilizer and on soil to which both were applied.

TABLE 7.—*Relative yields of crops on each soil sample when not limed and when both limed and fertilized.*

Type	No fertilizer, no lime	NPKL
Ontario and Honeoye		
Oneida County	100	173
Monroe County	100	215
Cato, Cayuga County	100	186
Sherwood, Cayuga County	100	153
Volusia		
Turkey Hill, Tompkins County	100	1,493
Cayuta, Tompkins County	100	385
Cortland County	100	421
Alleghany County	100	328
Dutchess		
Dutchess County	100	460
Orange County	100	948
Vergennes		
Washington County	100	202
Jefferson County	100	163

As shown by Table 7, there is an entire lack of uniformity in the response of samples within the soil type to the lime and complete

fertilizer treatment. This is to be expected because there is a wide difference in the need of some of these soil samples for lime as shown by the Veitch and other methods. The table may be dismissed with the observation that it does not add anything to support the idea that a soil type is uniform in its fertilizer response.

RESULTS ON SOME OF THE ILLINOIS EXPERIMENT FIELDS

Reports of fertility tests on the outlying experiment fields of the Illinois Agricultural Experiment Station disclose the fact that there are three soil types on which two or more experiment fields are located (2, 3, 4, 5). As the fertilizer treatments were similar on certain of the fields located on three soil types an opportunity is offered to study the uniformity of the effect of these treatments on crop yields.[4] These are the only published experiments of the kind that the writer has been able to find and they are a correspondingly valuable contribution to the study he has attempted to make.

Six experiment fields, namely, Odin, DuBois, Oblong, Newton, Toledo, and West Salem, are situated on a soil type known as "Gray silt loam on tight clay." It is a light-colored upland soil developed on loess. It is old and very acid with an impervious non-calcareous subsoil.

Three experiment fields are on "Muscatine silt loam." These are Dixon, Kewanee, and Lamoille. The soil of the Dixon field is a dark soil with open non-calcareous subsoil, and is described as "semi-mature." The Kewanee soil is similar, but possibly younger. Lamoille is somewhat heavier than the other two and is slightly acid.

Two fields are on "Grundy silt loam." They are Aledo and Clayton. The type is described as a very dark upland soil developed on loess.

The soil treatments and their designations used in Table 8 are as follows:

R = Crop residues.
RL = Crop residues, limestone, the latter applied at the rate of 1,000 lbs. per acre once during the rotation.
RLP = Crop residues, limestone, rock phosphate, the last applied at rate of 500 lbs. per acre once during the rotation.
RLPK = Crop residues, limestone, rock phosphate, and kainit, the last applied at the rate of 200 lbs. per acre once during the rotation.

[4]The writer wishes to express his obligation to John Lamb, Jr., for his help in analyzing the Illinois reports referred to, and in furnishing descriptions of the soil types.

In most cases the crop rotation consisted of wheat (sweet clover), corn, oats, and red clover. The sweet clover was seeded in the wheat during the late winter or early spring and turned under for corn in the following spring.

The relative yields of all crops on those series of plats having comparable treatments during the same years are shown in Table 8.

TABLE 8.—*Relative yields of crops on the same soil types in response to phosphorus and to potassium.*

Location	RL	RLP	RLP	RLPK
Gray Silt Loam on Tight Clay				
Oblong	100	112	100	108
Toledo	100	105	100	122
Newton	100	127	100	118
West Salem	100	134	100	115
Odin	100	121	100	130
DuBois	100	137	100	126
Muscatine Silt Loam				
Dixon	100	109	100	104
Kewanee	100	110	100	104
Lamoille	100	101	100	94
Grundy Silt Loam				
Aledo	100	107	100	98
Clayton	100	105	100	105

Considering first the fertilizer tests on Gray silt loam on tight clay, it is evident that large discrepancies exist in the crop response to both phosphorus and potassium. The maximum variation for phosphorus is 32% and for potassium 22%. On the other two soil types there is less variation, but differences of 8 to 10% occur.

DISCUSSION

In the light of these experiments it would not appear to be always possible to determine with accuracy the fertilizer needs of an entire soil type by means of experiments at any one locality. To what extent fertilizer trials should be conducted with a view to applying the results to the type in general is a fair question. For instance, should we attempt to differentiate between applications of 300 and 400 pounds of superphosphate in the course of a crop rotation, and should we make similar rather small distinctions for other fertilizer constituents?

It is not assumed that the responses of the New York soils under the conditions of this experiment would be the same as if they were tested *in situ*, but it is to be expected that they would respond more uniformly under the conditions of this experiment than they would as they occur in their respective localities where drainage, altitude, temperature, and perhaps other conditions may vary greatly. Since

the chances are that the responses of the samples as they occur in the field would be more divergent than this experiment shows them to be, the experimental errors in this test would probably be at least offset by this variation.

It may be asked whether it is worth while to try to distinguish between soil types of the same class in the application of fertilizers. Whether, for instance, the fertilizer treatment should not be adjusted for the crop to be grown, considering only the soil class and ignoring the series. The results of the experiments indicate that this does not hold for all types. Thus, it will be noticed in Table 3 that the response of Ontario and Honeoye soils to phosphorus was distinctly greater than that of Volusia. Only one sample of Volusia responded as strongly as did the least responsive sample of Ontario. Another outstanding case is the response of Dutchess to potassium. On no sample of the other three soils was potassium as effective as on either of the samples of Dutchess.

In the Illinois experiments the response of Gray silt loam on tight clay to potassium was greater in every sample than it was to any sample of Muscatine silt loam or Grundy silt loam. It must be concluded that there are some soil types of approximately the same class between which there are sufficient differences in response to the same plant nutrient to call for different sized applications of that fertilizer constituent. On the other hand, there were other soil types which responded so similarly to all fertilizer constituents that it is unnecessary to distinguish between them in applying fertilizer.

The heterogeneity of many soil types with respect to fertilizer response emphasizes the need for many more tests of each soil type than is practicable with field trials. It will generally be admitted that field experiments will afford more information than merely the fertilizer needs of a particular soil. When used solely for that purpose they are unwieldly and cannot be repeated on enough fields to give each farmer a knowledge of his soil. They need to be supplemented by other tests that can be carried out in the laboratory or greenhouse with reasonable celerity.

SUMMARY

The investigation was begun with the intention of measuring the fertilizer responses of a number of soil samples of the same type. It was expected that this would show what reliance might be placed on a single field experiment to represent the fertilizer requirements of the type as a whole.

Four types of soil were selected for the experiment. Of these four samples of each of two types were obtained from widely separated

areas, as were two samples of each of two other types. Each sample consisted of between 9 and 10 tons of soil and subsoil to a depth of 3 feet. They were placed in galvanized iron rims imbedded in the ground. Each sample filled 14 rims to which were applied certain fertilizer treatments. They were all cropped for 9 years and the yields recorded each year.

All samples that were tested for response to single fertilizer ingredients were limed to meet their requirements by the Veitch method. The crop response to these plant nutrients showed considerable discrepancies between samples of some of the types. The variations were so large as to raise a question regarding the sufficiency of the test on a single field to indicate the needs of the type in general.

Reports of the fertilizer tests on outlying fields of the Illinois Experiment Station were reviewed. Five of the fields were situated on one soil type, three on another type, and two on a third soil type. Similar discrepancies were found in the response of fields of the same type to certain fertilizer constituents. As in the New York soils some types gave rather uniform responses. In the light of these experiments it would not appear to be always possible to determine with accuracy the fertilizer needs of an entire soil type by means of experiments in one locality.

It may be asked whether it is worth while to try to distinguish between soil types of the same class in the application of fertilizers, or whether all types should receive the same treatment? The results of the experiments indicate that the latter does not hold for all soil types. In some cases all samples and fields of a given type responded more markedly to a given fertilizer ingredient than did any sample of another type. On the other hand, there were other soil types that responded so similarly to all fertilizer constituents that it is unnecessary to distinguish between them in applying fertilizer.

The experiments emphasize the need for many more tests of each soil type than is practicable with field trials.

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FERTILIZING CONIFEROUS SEEDLINGS[1]

A. C. McIntyre and J. W. White[2]

In a previous article by the authors[3] data were presented showing the effect of various fertilizer treatments on the growth and development of coniferous seedlings. The pitch pine (*Pinus rigida* M.) field plats, on which these data were obtained, were carried over for 2 additional years, and the data presented in Table 1 give growth values on these 4-year-old seedlings.

Dried blood at the rate of 400 pounds per acre produced the largest seedlings at both 2 and 4 years. At both ages the seedlings responded to increased amounts of dried blood (D. B.), ammonium sulfate (N ams), nitrate of soda (Na), muriate of potash (K_2O), and superphosphate (P). Where mixed fertilizers were used, the change in growth rate was more pronounced and less consistent. In the Na-K beds the response was much greater at the end of the fourth year, though the average weight of the seedlings was much less than those of the check plats.

Plat 19 moved up from 21st place at the end of 2 years to 3rd place in 4 years; plat 20 from 20th place to 7th; and plat 21 from 17th to 10th place. These plats showed the greatest response at the end of the fourth growing season.

Plat 3 treated with nitrate of soda at the rate of 200 pounds per acre showed the greatest decrease in growth dropping from fourth place at the end of the second year to 12th place in the fourth year. Nine plats maintained approximately their same relative ranking, gaining or losing only one place based on the average weight of samples of the 2- and 4-year-old seedlings.

The four check plats moved from 19th to 16th place. Thus, 9 plats at the end of the second year showed increased growth over the check plats, and at the end of the fourth year 11 plats exceeded the check plats.

At the end of this 4-year period, the plats were destroyed and composite soil samples were taken. These samples were screened

[1]Contribution from the Department of Forestry, Pennsylvania State College, State College, Pa. Publication authorized by the Director of the Pennsylvania Agricultural Experiment Station as Technical Paper No. 528. Received for publication May 27, 1931.

[2]Instructor in Forest Research and Professor of Soil Technology, respectively.

[3]McIntyre, A. C., and White, J. A. The growth of certain conifers as influenced by different fertilizer treatments. Jour. Amer. Soc. Agron., 22: 558–567. 1930.

TABLE 1.—*Effect of fertilizer treatments on growth of 2- and 4-year-old coniferous seedlings.*

Plat No.	Treatment*	Rate in lbs. per acre	Soil acidity, pH value	Average weight of seedlings, mgm	
				2-year-old pitch pine	4-year-old pitch pine
1	Na	100	6.83	368	1,356
2	Na	150	6.31	284	1,108
3	Na	200	6.53	292	1,412
4	D.B.	200	5.75	399	1,556
5	D.B.	300	6.53	463	1,768
6	D.B.	400	6.01	545	2,496
7	N (ams)	100	5.82	369	1,536
8	N (ams)	200	6.09	436	1,696
9	N (ams)	400	5.68	506	1,744
10	P	400	5.84	236	1,048
11	P	600	6.06	311	1,204
12	P	800	6.32	374	1,688
13	K	100	5.81	241	1,112
14	K	150	5.97	304	1,132
15	K	200	6.78	348	1,412
16	Na, 100; P, 400	500	6.45	320	1,416
17	Na, 150; P, 600	750	6.11	374	1,420
18	Na, 200; P, 800	1,000	6.99	361	1,384
19	Na, 100; K, 100	200	6.02	417	1,068
20	Na, 150; K, 150	300	6.54	400	1,184
21	Na, 200; K, 200	400	6.16	391	1,284
22	P, 400; K, 100	500	5.91	311	960
23	P, 600; K, 150	750	6.09	321	1,216
24	P, 800; K, 200	1,000	7.65	486	2,128
25	Na, 100; K, 100; P, 400	600	5.82	484	1,448
26	Na, 150; K, 150; P, 600	900	—	481	—
27	Na, 200; K, 200; P, 800	1,200	5.92	380	1,712
28	Check	—	6.17	397	1,428

*Na = Nitrate of soda; P = Superphosphate; K = K_2O (muriate of potash); D.B. = Dried blood; N (ams) = Ammonium sulfate; L = Lime.

and three 4-gram samples taken on which pH values were determined. Each sample was allowed to stand for about 24 hours in 8 cc of distilled water, and acidity values were determined by using the saturated calomel quinhydrone cell. These acidity values are presented in Table 1. The four check plats varied in their values by 0.4; the average values are given. On the whole, these values are consistent and indicate the trend of the various fertilizers in influencing soil acidity on this Hagerstown silt loam.

It is apparent, from the data presented, that varying responses may be expected from pitch pine seedlings when left in fertilized seedbeds for varying lengths of time. This is probably due to certain fertilizers going into solution more slowly, or to the gradual removal of toxic concentrations of certain fertilizers. As measured by the samples taken during the second and fourth years, dried blood produced the largest and heaviest seedlings.

A NEW MODIFICATION OF THE THREE-COMPARTMENT ELECTRODIALYSIS APPARATUS[1]

AASULV LÖDDESÖL[2]

Numerous publications dealing with the exchangeable cations of the soil have appeared in the last few years. Most of the investigations which have been performed in order to determine the amount of exchangeable cations present in soils have been based on the neutral salt extraction method used by Way (17, 18)[3] as early as 1850. The underlying principle of this method is the replacement of the adsorbed cations of soil colloids by cations of the salt solution used. Then, by chemical analysis, the cations which enter the solution can be ascertained.

Extraction of the adsorbed cations of soil colloids has also been made by the use of dilute acids. In this case the hydrogen ions of the acids replace the base cations of the soil colloids. The latter will then be saturated with hydrogen ions.

A relatively new phase in the field of soil investigation is the use of electrodialysis in the study of exchangeable cations in the soil. Again, the base cations of soil colloids in water suspension are replaced by hydrogen ions from water which contains carbon dioxide. This exchange process is brought about by the application of an electric current. Electrodialysis can consequently be defined as an electrical transportation of ions through suitable membranes which do not allow the passing of colloids [cf. Pauli (15)].

The process of electrodialysis of soil is briefly as follows: First, distilled water is added to the soil sample to be studied. The suspension formed is then placed in a central chamber which is separated from side chambers by means of membranes. Electrodes are placed in the side chambers, which are filled with distilled water, and then a direct current is applied. By such an arrangement there results an apparatus consisting of three compartments, *viz.*, a middle chamber, a cathode chamber, and an anode chamber. It might be mentioned here that there exists another type of apparatus in which the anode electrode is placed in the suspended soil. With the latter arrangement we have a two-compartment cell.

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication June 12, 1931.

[2]Instructor in Geology and Soils, Agricultural College of Norway. This paper was prepared by the writer while a Resident Doctor at Cornell University and a Fellow of the Rockefeller Foundation.

[3]Reference by number is to "Literature Cited," p. 81. A relatively complete list of literature dealing with investigations of the exchangeable cations in the soil is given in a previous publication of the author (9).

Since the soil suspension is a conductor of electricity, due to its content of electrolytes, a movement of ions, especially hydrogen ions, takes place as soon as the electrical circuit is completed. The continuous movement of hydrogen ions through the soil suspension results in a gradual replacement of the base cations of the soil. The replaced cations, which migrate to the cathode, will form hydroxides in the cathode chamber with a liberation of hydrogen. This process involves all the adsorbed base cations, except ammonium ions, which, to a certain extent, might be liberated as ammonia gas.

The anions which are set free, such as Cl^-, CO_3^{--}, SO_4^{--}, PO_4^{---}, etc., migrate to the anode and there form acids. A part of certain of the anions, as for example Cl^-, HCO_3^-, CO_3^{--}, will be liberated as gases, while the amount of SO_4^{--}, PO_4^{---}, etc., can be determined by chemical analysis of the anode water.

REQUIREMENTS OF THE ELECTRODIALYSIS APPARATUS

The requirements of an electrodialysis apparatus differ in its various uses. In general, it can be stated, that the apparatus must be capable of reproducing results. It is desirable also to have a rapid exchange of ions, and at the same time have all disturbing factors eliminated. It is also important to have an apparatus which requires a minimum amount of attention while in use. The requirement as to the size of the apparatus will vary according to the experiment to be performed. Especially with so-called fractional electrodialysis, as noted by Odén and Lóddesol (13), it is desired to have an apparatus with a middle chamber of large capacity.

The requirements for a rapid ionic exchange can be met by setting the electrodes close together, by using a relatively dilute suspension and by increasing the voltage. A more complete replacement of the exchangeable ions is also facilitated by an effective stirring of the soil suspension.[4]

The processes which take place under electrodialysis result in a rather striking rise in the temperature, especially in the middle compartment. Therefore the apparatus should be cooled in such a manner as to give a constant temperature. This will eliminate errors which would otherwise be due to secondary reactions, such as the decomposition of organic materials.

This complexity of requirements is difficult to meet in the same apparatus, as technical difficulties are seen to arise. The ideal apparatus must possess structural features which will permit a wide adaptability in its use.

[4]Results of investigations concerning factors which affect the rate of replacement of ions will be published later.

TYPES OF APPARATUS

Humfeld and Alben (8) have given a review of literature concerning electrodialysing apparatus. Therefore, this paper will mention only those types of apparatus which are chiefly applied to soil research work, and also those which have appeared after the foregoing authors' paper was published.

Odén (12) has constructed two types of dialysing cells termed by him as model A and model B. Of these two models, B is of greater interest. The most important characteristics of this apparatus will therefore be mentioned. It consists of cylindrical middle and end chambers made of heavy glass. The apparatus is made in two sizes, having middle chambers of 800-cc capacity and 2,500-cc capacity. To avoid heating, tap water is run through a spirally constructed glass tube which has been inserted into the soil suspension. In the center of the vertical spiral is placed a motor-driven stirrer which keeps the soil suspension in constant circulation. This apparatus has proved to be of great value in the electrodialysis of large samples of soil.[5]

Pauli's (15) three-chambered cell, originally constructed for purifying colloids and later improved by Bradfield (3), has also found entrance into the field of soil investigation. Bradfield's modification is made of Pyrex glass and has, like Odén's apparatus, a cylindrical middle chamber. The capacity of the middle compartment is about 110 cc.

Trénel (16), in his investigation of permutit, has also used a modification of Pauli's apparatus but of a larger capacity than Bradfield's. In these apparatus no cooling systems have been applied. The rise in temperature has been controlled by incorporating a resistance in the electrical circuit in series with the apparatus.

Mattson (11), who has constructed a three-compartment cell of a distinctly different type[6] from those previously mentioned, also makes use of a resistance arrangement in order to keep down the temperature.

However, Humfeld and Alben (7), who worked with Mattson's cell, placed grids made of glass tubes both in the center compartment and on each side of the membranes and allowed cold tap water to run through the grids continuously to avoid overheating.

[5]After this paper was written Odén and Wijkström (14) have presented a new type of the three-compartment electrodialysis apparatus made of teak wood. The most interesting feature of the new cell is the size of the end chambers, which only contain about 40 cc of liquid, whereas the middle compartment has a capacity of 600 to 800 cc.

[6]This cell is described by Humfeld and Alben (7).

Bradfield (2) has constructed an inexpensive cell similar to Mattson's where a resistance arrangement again is used.

An apparatus constructed by Holmes and Elder (6), of the three-compartment type, has a relatively long cylindrical middle chamber. The anode and cathode chambers consist only of a number of filter papers placed between the membranes and the electrodes through which distilled water is continually seeping. The dialysates, with the ions extracted from the medium in the middle chamber, are then collected in funnels and carried to storage bottles. The stirring is accomplished by means of carbon dioxide-free air which bubbles out from a tube placed in the middle chamber.

Bradfield (1), in addition to his two types of three-compartment apparatus, has constructed a two-compartment electrodialysis cell which has been used to a certain extent in soil research work. A modification of this cell is presented by Crowther and Basu (4).

A simple apparatus based on the two-compartment principle constructed by Marikovsky and Lindner (10) for milk investigation has been used in the electrodialysis of soil samples by Herzner (5).

With the two-compartment cells the anions are not separated from the soil suspension. The latter therefore soon becomes acid, a condition which probably leads to a solution effect on the soil particles.

A NEW MODIFICATION OF THE THREE-COMPARTMENT ELECTRODIALYSIS APPARATUS

The apparatus which is shown in Fig. 1 has a globular-shaped middle chamber. This form of bulb imparts not only a large volume, but also makes it possible to have a relatively short distance between the electrodes. The relation between the volume of the globe and the distance between the electrodes can be varied, however, since the flanges on the globe, which connect the middle chamber with the end chambers, might be constructed at different distances from the vertical axis of the middle chamber. It is assumed that the electrodes are to be placed close to the membranes which separate the different chambers.

The apparatus shown in Fig. 1 has a middle chamber with a capacity of 450 cc and has a distance of 8 cm between the outside edges of the flanges. If the distance between the flanges is made 6 cm, a bulb of about 250-cc volume is obtained.

The globular-shaped middle chamber permits a very effective stirring of the soil suspension, since corners are eliminated. Thorough circulation of the soil suspension can be obtained by using a stirrer, as

shown in Fig. 2. As previously mentioned, this will promote a more complete and rapid replacement of the exchangeable cations.

As seen in Figs. 1 and 2, the middle chamber has an enlarged or globular neck. This serves as a reservoir, since the level of the soil suspension in many cases rises during the process of electrodialysis. This is due to a passing of water through the membrane from the anode chamber. A smaller movement of water from the middle

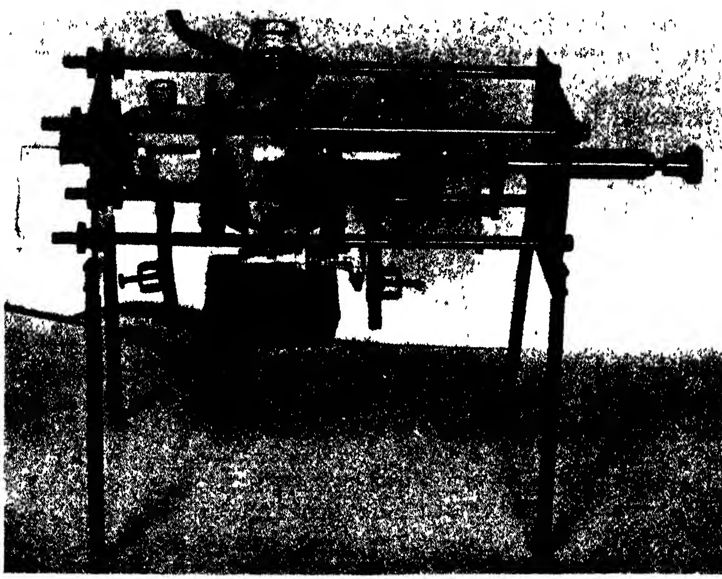

FIG. 1.—Electrodialysis apparatus.

chamber to the cathode chamber is also observed by using soils rich in base cations. Since the cathode water can be tapped at any time during the experiment it is not necessary to enlarge the neck of that chamber. The extent to which water passes through the membranes depends partly upon the types of membranes used. It is believed that the reason for this behavior is partly due to differences in ion concentration in the chambers, and that the passing of water through the membranes is in part an osmotic phenomenon. The reservoir reduces the danger of losing any part of the soil suspension, thus necessitating a minimum amount of attention during the experiment.

As membranes, parchment should be recommended at the cathode and cellophane at the anode. By such an arrangement the flow of water from the anode chamber to the middle chamber is found to take place to a less extent than when parchment is used as anode

membrane. This must be due to electroendosmosis, which should take place to a greater extent for cellophane than for parchment as anode membrane.[7] The effective size of the membranes in the described apparatus is about 30 cm^2.

The middle chamber is furnished with a ground glass stopcock. By means of this stopcock the soil suspension can be changed and the

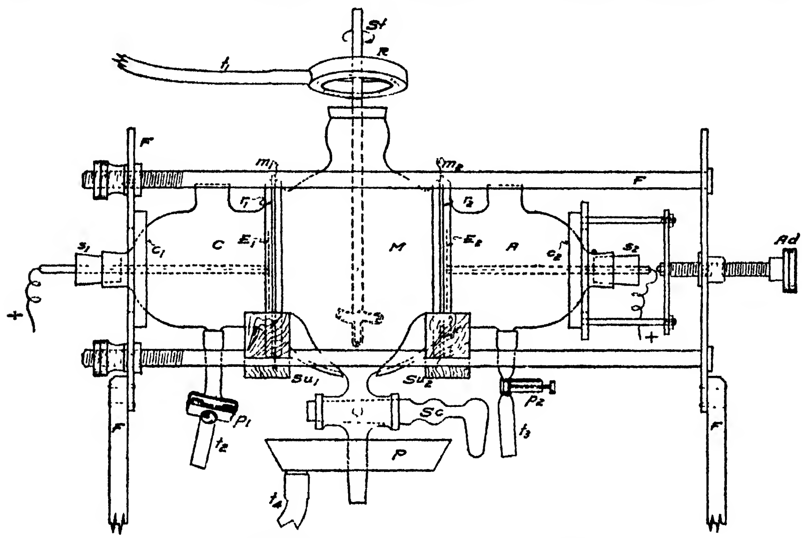

FIG. 2. -Diagram showing construction of apparatus.

M = middle chamber.
A = anode chamber.
C = cathode chamber.
E_1 and E_2 = electrodes.
m_1 and m_2 = membranes.
r_1 and r_2 = rubber gaskets.
St = stirrer.
Sc = stopcock.
R = perforated metal ring.
Su_1 and Su_2 = wooden supports with crescent-shaped gutter.
P = pan with outlet.
F - - F = frame.
Ad = adjusting screw.
s_1 and s_2 = rubber stoppers.
c_1 and c_2 = rubber cushions.
t_1, t_2, t_3, and t_4 = rubber tubings.
p_1 and p_2 = pinchcocks.

bulb drained and cleaned at the end of an experiment with a minimum of trouble. The stopcock must be placed as close to the bulb as possible in order to keep all the soil suspension in circulation.

The cooling system of the new apparatus is of special interest. It is seen from Fig. 1 that a metal ring is placed around the neck of the middle chamber. This ring, which is made of brass, is hollow and has a series of holes on its under edge. Cooling water is then applied and runs out smoothly from the holes in the ring to envelop the glass bulb completely with a layer of cold running water. Aided by the

[7]In a later publication the influence of different types of membranes will be discussed.

use of two crescent-shaped gutters, the cooling water is collected in and continuously drained from a pan beneath the apparatus. The pan is made of copper and is fastened to the draining tube of the middle chamber by means of a one-holed rubber stopper.

This cooling system has proved very effective. Even with electrodialysis of materials very rich in adsorbed base cations, the temperature has been held to about 20°C. The effectiveness of the cooling system will evidently depend on the temperature of the cooling water itself and also upon the amount used. Due to the chemical processes which take place in the end chambers the temperature of these chambers in certain cases also rises to such a degree that it is necessary to reduce it. By a gradual and continuous change of water in the end chambers this increase in temperature can be controlled. This procedure has been followed by Odén (12).

This system of cooling eliminates the need for any form of resistance in the electrical circuit. On the contrary, an increased voltage can be used with a consequent increase in amperage, and still effective cooling is obtained.

In other respects the construction of the apparatus differs only slightly from Bradfield's modification. The capacity of the end chambers of the apparatus, seen in Fig. 1, is 125 cc. Platinum rhodium is used both for anode and cathode electrodes. The diameter of the electrodes is 4 cm. The middle chamber as well as the end chambers are made of Pyrex glass. The frame is made of brass and its construction can be seen from the photograph.[8]

SUMMARY

A brief review of the principle of electrodialysis used in the investigation of the exchangeable bases in soils is given.

Requirements as to the types of apparatus are discussed. In addition, references to literature are given where different types of electrodialysis cells are presented.

A new modification of the three-compartment electrodialysis cell is described. The apparatus presented has worked satisfactorily and has shown itself capable of reproducing results.

[8]The glass work of the apparatus was originally made by A. L. Brandt, Baker Laboratory, Cornell University, Ithaca, N. Y., and subsequently by the Corning Glass Works, Corning, N. Y. The metallic work was performed by H. S. Bush of the Baker Laboratory. Arrangements have been made with the Central Scientific Company of Chicago for the manufacture and sale of this apparatus.

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NOTE

PLANT ROOT DEVELOPMENT AND DISTRIBUTION BY SOIL TYPE

Soil scientists and ecologists are likely to find in the paper, "Some Studies of Root Habits of Sugar Cane in Cuba," recently published as Scientific Contribution No. 21, Tropical Plant Research Foundation (1086 N. Broadway, Yonkers, N Y.), by James H Jensen, some very interesting fundamental data pertaining to the effect of soil environment on root development and distribution of sugar cane. These studies relate to root distribution, as actually plotted through the soil profile, at ages of 4, 6, and 10 to 11 months on a very dense, plastic clay (Alto Cedro clay), a moderately friable clay, containing an increasing amount of sand downward (Rio Cauto clay); a highly porous clay of lateritic character (Francisco clay); and a clay with a hardpan-like subsoil and high water table (Navajas clay).

The marked effect of these widely different soil characteristics are strikingly brought out in this paper. It is shown that soil type plays a very important rôle in relation to correct tillage and planting methods For example, the root development of Alto Cedro clay is largely in the surface zone, indicating the necessity for keeping this fact in mind in connection with cultural operations; whereas, on Rio Cauto clay the roots strike downward into the more friable subsoil material to a very much greater degree. The soils discussed in this paper are described briefly and are more fully described in *The Soils of Cuba* (Tropical Plant Research Foundation).

Another recent publication by the Tropical Plant Research Foundation, "The Utilization of Varieties in the Field Control of Sugar Cane Mosaic and Root Disease in Cuba" (Scientific Contribution No. 20), by James A. Faris, formerly of the Foundation and now of the U. S Dept of Agriculture Bureau of Plant Industry, relates pertinently to variety tests and spacing and cultural tests of sugar cane on a large number of definite soil types It is significant that the results of these tests do not stop merely with the obtaining of yields but are carried on to the finished manufactured product, giving the final outturn of sugar, as well as the purity, Brix and sucrose content of the cane juices, as measured in the mill. This is a type of experimental work which differs from most experiments in that the results are carried on beyond the point of production — H. H. BENNETT, *U. S. Dept of Agriculture, Washington, D. C.*

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NEWS ITEM

DR. EMIL TRUOG of the University of Wisconsin will give a series of six daily lectures on soils, plant nutrition, and fertilizers at the Massachusetts State College during the week of February 14–20. The topics in order of presentation will be as follows: The soil system; soil formation and important characteristics of soils; soil and plant relations; fertilizer reactions in soils; methods of fertilizer application; and determination of fertilizer needs of soils.

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A COMPARISON OF HAND AND WIND POLLINATION IN MAKING F_1 CROSSES BETWEEN INBRED LINES OF CORN[1]

I. J. JOHNSON and H. K. HAYES[2]

The method of corn improvement through hybridization which is now being used by most of the experiment stations has been limited in many instances by the difficulties involved in the commercial production of hybrid seed and the increase of the parental lines. The double-cross method requires that three crosses be made and inbred lines must be used for two of the three crosses. The importance of learning the most satisfactory means of making these first crosses is apparent.

During 1930 an extensive series of single crosses was made at University Farm, St. Paul, Minnesota, to obtain a seed increase and to determine the best methods for making the first crosses to be used in more extensive production of the three double-crosses E x I, E x K, and E x L. The results of these studies form the basis of this paper.

MATERIALS AND METHODS

The four single crosses E, I, K, and L are made by crossing cultures 11 x 14, 16 x 20, 15 x 19, and 21 x 22, respectively. Data regarding these cultures are given in Table 1.

The F_1 crosses between these cultures were made by controlled hand pollination and by wind pollination in isolated crossing plats. In the plats used to make crosses by hand pollination a ratio of two rows of the staminate to one row of the pistillate parent was used. Enough pollen was obtained in this ratio to pollinate all the ears of the pistillate parent and to sib-pollinate all ears of the staminate

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Paper No. 1021, Journal Series, Minnesota Agricultural Experiment Station. Received for publication May 29, 1931.

[2]Instructor and Chief, respectively.

parent. To facilitate the work of pollination, pollen was collected from a number of plants, sifted through a fine screen, and applied to the silks by means of an insect duster.

TABLE 1.—*Data regarding cultures used in Minnesota crosses.*

Culture No.	Variety	Years selfed	Yield in % of normal, 1928	Plant height, 1928–30, in.	Ear length, 1928–30, in.
11	Minn. No. 13	7	44	66	5.3
14	Minn. No. 13	13	27	54	3.8
16	Rustler	8	35	58	5.3
20	Rustler	9	25	59	4.8
15	Rustler	8	42	63	4.8
19	Rustler	10	39	63	4.8
21	N. W. Dent	9	31	65	4.5
22	N. W Dent	9	41	56	4.8

The wind-pollinated crosses were made in small plats well isolated from other corn fields. The ratio of staminate to pistillate parents ranged from 1:3 to 2:1. The plats were visited each day and tassels of the pistillate parent were removed before any of their pollen had been shed. In addition to the crossing plats at University Farm, two isolated plats were grown under contract with farmer cooperators.

The cost data were obtained from carefully kept records of the actual number of hours and material used on each cross. The detailed work was directed by graduate student assistants paid at the rate of $150 per month. Other work under their supervision was paid for at the rate of 30 cents per hour. General expenses, which include such items as seedbed preparation, planting, cultivating, etc., are somewhat higher than found under usual farm conditions because of the larger amount of hand labor. Ear and tassel bags used in the hand pollination study were purchased at $4.60 and $2.85 per thousand, respectively.

In the hand pollination plats, the cost of producing crossed seed does not include the cost of maintaining the parental lines. The cost of producing the first crosses by wind pollination includes the cost of obtaining sibbed seed of the staminate parent.

EXPERIMENTAL RESULTS

The results secured from the different crossing plats are summarized in Tables 2 and 3. Although the yields secured are low because of the adverse weather conditions, it is probable that they give a fair indication of the sort of results which might be secured with these cultures under more favorable conditions.

TABLE 2.—*Cost of producing single crossed seed by hand pollination, University Farm, St. Paul, Minn., 1930.*

Cross	Area in acres	Items of expense			Total Cost	Seed obtained, lbs.	Cost per lb.*	Kernels per ear
		General	Pollination	Bags				
11 x 14 = E	0.19	$5.14	$6.19	$1.63	$12.96	23.0	$0.56	111
20 x 16 = I	0.13	3.51	4.18	1.28	8.97	10.0	0.90	69
19 x 15 = K	0.13	3.51	5.19	2.51	11.21	4.8	2.34	39
21 x 22 = L	0.13	3.51	3.71	1.44	8.66	7.0	1.24	71

*Weighted average cost per pound, $0.93.

The cost of producing crossed seed by hand pollination, given in Table 2, is approximately the same as that found in a preliminary study made in 1929. During the previous year, the average cost of producing seed of the same crosses was approximately $1.00 per pound as compared with the 1930 average cost of 93 cents. The costs during 1930 ranged from 56 cents per pound in the cross 11 x 14 to $2.34 per pound in the cross 19 x 15. This wide difference is largely brought about by differences in yielding ability of the pistillate parents. Culture 11 produced 23 pounds of hybrid seed on 0.19 acre with an average of 111 kernels per ear, while culture 19 produced only 4.8 pounds of seed from 0.13 acre and averaged 39 kernels per ear.

TABLE 3.—*Cost of producing single crossed seed by wind pollination, University Farm, St. Paul, Minn., 1930.*

Cross	Area, acres	Ratio of ♂ : ♀	Items of expense				Seed obtained, lbs.	Cost per lb.†	Kernels per ear
			General	Detasseling	Travel	Total cost			
11 x 14 = E	2.00	3:2	$49.06	$7.92	$7.30	$64.28	149.4	$0.43	41
14 x 11 = E	0.70	2:1	17.24	3.42	2.56	23.22	59.6	0.39	88
20 x 16 = I	2.10	2:1	51.72	8.82	7.67	68.21	242.8	0.28	64
19 x 15 = K	0.55	1:3	13.55	4.32	2.01	19.88	71.8	0.28	48
21 x 22 = L	0.45	1:3	11.08	6.12	1.64	18.84	105.4	0.18	46
16 x 20 = I*	0.55	2:1	3.50	——	——	18.50	111.5	0.17	—
20 x 16 = I*	0.50	2:1	3.50	——	——	18.50	113.5	0.16	—

*Grown under contract by farmer cooperators.
†Weighted average cost per pound, $0.27.

The cost of producing crossed seed by the use of isolated plats and detasseling is given in Table 3. The calculated costs of seed ranged from 43 to 16 cents per pound. The average cost of 27 cents shows that wind pollination in isolated plats is far more economical than hand pollination. The advantage cannot be attributed to a more successful seed setting, since on the average, the number of kernels per ear is nearly the same. In the cross 11 x 14, the better seed setting

by hand pollination is due primarily to differences in soil type of the two plats. The wind-pollinated plat used for this cross was on sandy soil and the plants suffered considerable injury from dry weather. The soil type of the other wind-pollinated plats was quite similar to the one used in the hand pollination study.

An analysis of the items which make up the average total cost of production shows that in the hand pollination plat general expenses constitute 37.5%, hand pollination 46.1%, and the ear and tassel bags 16.4% of the total cost of production. In the wind pollination plats grown at the University Farm, general expenses constitute 73.4%, travel 10.9%, and detasseling 15.7% of the total costs of production. The difference in amount of hand labor and material used by the two methods largely accounts for the differences in cost of producing hybrid seed. The relatively low cost of producing single crossed seed on the cooperative plats is due largely to the high yields obtained. The isolated plats used by the cooperators received heavy applications of barnyard manure, and in one of the plats commercial fertilizer also was applied. The favorable response suggests a means of reducing the cost of producing hybrid seed by the use of liberal applications of fertilizers.

Since the above crosses had not been made previously by wind pollination, additional studies were made to determine if sufficient pollen had been produced by the staminate parent to provide for maximum pollination and to determine the value of hand pollination as a supplement to wind pollination. Tassels of the staminate parent were bagged at random throughout each field and the collected pollen applied by means of an insect duster to the uncovered silks of all plants in certain rows of the pistillate parent. Adjacent rows were left untreated to check the influence of the supplementary pollen on the average number of kernels per ear and yield of shelled corn. The data given in Table 4 indicate that the staminate plants failed to supply enough pollen for maximum pollination. The addition of supplementary pollen not only gave increased seed setting and increased yield in all crosses, but also gave in most cases an increased number of ears per row as shown by a comparison of the percentage increase in seed setting and the percentage increase in weight of seed produced (Table 4).

These results indicate a need for further study to determine the correct ratio of staminate to pistillate parents in each cross. In making the cross of 21 x 22 with a ratio of 1 row of the pollen parent to 3 rows of the ear parent, an increase of only 21.7% was secured from the supplementary pollen indicating that in this cross nearly

enough pollen was produced by the single staminate row to pollinate 3 rows of the pistillate parent. In the cross 14 x 11, two rows of the staminate parent failed to produce enough pollen to pollinate properly a single row of the pistillate parent as shown by the increase of 93.1% in weight of corn obtained by adding supplementary pollen.

TABLE 4.—*Effect of additional pollen applied to wind-pollinated pistillate plants.*

Cross	Ratio of ♂ : ♀	No. of plats compared	Average number of kernels per ear			Total weight of corn			Cost per pound of increase*
			Treated	Check	Increase %	Treated	Check	Increase %	
11x14	3:2	2	52.1	40.9	27.4	28.4	23.4	21.4	$1.76
14x11	2:1	3	164.4	88.2	86.4	25.1	13.0	93.1	0.66
19x15	1:3	4	63.8	48.0	32.9	27.0	15.7	72.0	1.24
21x22	1:3	4	55.7	46.2	20.6	50.5	41.5	21.7	1.63

*Weighted average cost per pound of increase, $1.22.

Although the increase in weight of corn from the treated plats is quite high, cost studies show that the cost per pound of this increase is greater than the original cost by the use of isolated plats and detasseling the female parent. The lowest cost of 66 cents per pound of the increase was obtained in the cross 14 x 11, and the highest cost of $1.76 was obtained in the cross 11 x 14.

TABLE 5.—*Cost of producing single cross seed of sweet and pop corn by wind pollination, University Farm, St. Paul, Minn., 1930.*

Cross	Items of expense			Pounds of seed obtained	Cost per pound	Kernels per ear
	General	Detasseling	Total cost			
77 x 78	$4.38	$6.45	$10.83	78.0	$0.14	139
Other Golden Bantam F_1's.	1.19	.75	1.94	17.5	0.12	152
Pop corn F_1's	4.61	7.20	11.81	22.9	0.52	232

Additional data on the cost of producing F_1 seed by wind pollination were secured from a series of crosses between inbred lines of Golden Bantam sweet corn and between inbred lines of pop corn. One of the sweet corn single crosses, 77 x 78, was made to produce a hybrid suited for canning on the ear, this phase of corn breeding being a cooperative project with the Minnesota Valley Canning Company, LeSueur, Minnesota. A considerable quantity of seed of 77 x 78 was produced in 1931. Several other sweet corn single crosses were made in an isolated plat using one culture as the staminate parent in all crosses. A similar plan was used in making several F_1 crosses between inbred lines of pop corn. The summarized data on the cost of producing seed of these crosses are given in Table 5.

The cultures used in the above crosses are high enough in yielding ability to warrant their use for making commercial single crossed seed. Although a ratio of 1 staminate to 1 pistillate parent was used, it is quite likely that fewer staminate rows would have produced sufficient pollen for maximum pollination. The successful seed setting in the sweet corn as shown by the average number of kernels per ear is evidence of the adaptability of these lines to hybridization. This aided materially in reducing the cost of producing the hybrid seed. A few of the pop corn lines suffered considerably from lack of moisture and the average cost of producing these hybrids was probably higher than would be true for a season of normal rainfall.

SUMMARY AND CONCLUSIONS

Data are presented comparing the cost of producing F_1 crosses in field corn by wind and hand pollination methods. The results of these studies favor the making of these crosses by the use of isolated plats in which the pistillate parent is detasseled. Actual cost studies made in 1930 with four crosses gave a weighted average cost per pound of 93 cents for hand pollination and 27 cents per pound for wind pollination. These data secured under adverse moisture conditions apply specifically to the eight cultures used at University Farm, St. Paul, Minn.

Supplementary pollen was applied to certain rows of the pistillate parent to determine if sufficient pollen had been produced for maximum pollination in various ratios of staminate to pistillate parents. These results suggest a need for additional study to determine the most satisfactory ratio for each cross. Although the use of supplementary pollen gave an increase in yield of hybrid seed, cost studies have shown that the cost per pound of this increase is greater than the original cost by wind pollination methods.

The cost of producing F_1 hybrids of Golden Bantam sweet corn by wind pollination was less than for field corn. The sweet corn lines are vigorous enough to warrant their use for the commercial production of single crossed seed. The cross 77 x 78 has shown promise for canning on the ear and considerable hybrid seed was made in 1931.

The cost of producing single crosses from pop corn selfed lines was higher than for sweet or field corn, due primarily to unfavorable location of the crossing plat. The pop corn cultures appeared very vigorous and well adapted to the production of commercial single crossed seed.

RELATION OF STRAINS OF NODULE BACTERIA AND FERTILIZER TREATMENTS TO NODULATION AND GROWTH OF ALFALFA[1]

S. C. Vandecaveye[2]

Attempts have been made for several years to grow alfalfa in the various counties of western Washington. These counties are all situated in the humid area of the state, west of the Cascade Mountains, and it has been found that there are some difficulties in the way of raising alfalfa successfully on certain soil types. The origin and formation of the soils in this area are glacial, residual, and alluvial. Because of their formation under humid climatic conditions these soils have been subjected to considerable leaching, are somewhat acid in reaction, and in addition present many fertility problems.

The economic advantage of growing alfalfa in the dairy sections of western Washington is easy to understand when it is considered that one of the main items of expense for a considerable number of the dairy farmers is the purchase of good hay for feed during the winter months. On a few of the soil types of this area alfalfa can be grown fairly successfully without any exceptional difficulty in securing and maintaining a satisfactory stand, but this is rather the exception than the rule. While on many soil types a good stand of alfalfa may be obtained early in the season especially when the seed is planted without nurse crops, numerous yellowish spots make their appearance in the field later in the season and the crop in general lacks thrift and vigor. The following spring the alfalfa usually does not show up well and in many cases has a poorer appearance than the first year. If the farmer does not get discouraged and does not plow up the field, the alfalfa may manage to survive rather indifferently that year. If it does survive usually some improvement may be noted during the third season resulting in a fair but not a very satisfactory crop.

Proper soil reaction and adequate inoculation with nodule bacteria are generally conceded to be two very important factors in the suc-

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cessful growth of alfalfa. Liming of acid soils and inoculation with artificial cultures of nodule bacteria are well established practices which are considered essential and have given excellent results in many cases. That some soils are better adapted for alfalfa than others irrespective of reaction is recognized and has been emphasized by Sewell and Gainey (8).[3] Many investigators are of the opinion that certain soils are more easily inoculated with nodule bacteria than others and that different strains of nodule bacteria are not equally effective in various soil types and on the host plants. This is indicated by the work of Wilson (9), Scanlan (7), Helz, Baldwin, and Fred (5), and Harper and Murphy (4) who have reviewed the literature on the various phases of this subject, hence it requires no further consideration here.

Considering the information available in the literature, it was thought at first that some of the difficulties in growing alfalfa in western Washington might be attributable to unsatisfactory inoculation due partially to soil reaction and partially to poor adaptation of the strains of nodule bacteria used for seed inoculation. The experiments presented in this paper are in part concerned with this phase of the subject. Due to the fact that many soil fertility problems exist in certain soil types of this area, the possibility of adjusting the available plant food supply in the soil by the use of commercial fertilizers was also considered in this work.

PLAN OF THE EXPERIMENTS

In the spring of 1927, series of 25 small plats were laid out on various soil types of the Everett and Puget series in King, Snohomish, and Pierce Counties for the purpose of ascertaining the nodulation power of 24 strains of alfalfa nodule bacteria introduced into these soils by means of seed inoculation. The origin of the Everett series is glacial and that of the Puget series alluvial. During the previous year several of these strains had been isolated from plants taken from fields where alfalfa was growing successfully and from isolated alfalfa or sweet clover plants growing wild along the roadside or on uncultivated land in various counties of western Washington. The plants from which these cultures were isolated were all exceptionally well inoculated and the cultures obtained were tested in the laboratory for purity and in soil or sand cultures in the greenhouse for inoculating power. Only those giving the most promising results were selected for use in the plat experiments. Strains Pn, Pb, Pa, and Hc were derived from this source. The other strains were obtained from

[3]Reference by number is to "Literature Cited, p. 103.

our own laboratory stock cultures, from the culture collection of the Department of Agricultural Bacteriology at the University of Wisconsin, and from the commercial supplies of various commercial nodule bacteria culture laboratories in the United States.

Among these latter were strains B1, B20, B25, C1, F1, N1, O1, S1, and U1 selected from our own laboratory stock cultures; strains W5, W31, W40, and W106 secured from the Department of Agricultural Bacteriology at the University of Wisconsin; and strains F, H, Ma, Na, Nb, and U supplied by various commercial nodule bacteria culture laboratories. Cultures of these strains were used to inoculate the alfalfa seed at planting time at the rate ordinarily used for field practice or, in the case of commercial cultures, according to the directions accompanying the cultures.

An attempt was made to select well-drained fields in which alfalfa had never been grown before and soil types on which alfalfa was thought to grow with difficulty. The field plats in which these strains of alfalfa nodule bacteria were to be tested were rectangular in shape and had an area of approximately 0.01 acre. The inoculated seed was broadcast late in May without a nurse crop on a well-prepared, firm seedbed at the rate of 16 pounds per acre, which is the rate of seeding commonly used in this area. One foot strips between adjacent plats were left unseeded.

The results of this experiment at the end of the first growing season served as a basis for a second series of plats started in the spring of 1928. For this series of plats three soil types were selected on which alfalfa was known to grow very poorly and two soil types on which alfalfa had been growing successfully only in certain rare instances. The first three soil types included two of the Spanaway series and one of the Whatcom series. Both of these soil series are of glacial origin. The other two soil types included one of the Everett series and one of the Puget series. The Everett series is glacial and the Puget series is alluvial in origin. Typical fields of various soil types were selected on which alfalfa had never been seeded as far as could be learned from the owners. On each of these fields a series of 12 small plats measuring 6 by 62 feet, or approximately 1/100 acre in area, were laid out to test the different strains of alfalfa nodule bacteria. The strains used were the ones which had shown the most promising results in the previous experiment with the exception of those supplied by the commercial laboratories which were used irrespective of the results obtained in the previous test.

Across each set of 12 plats commercial fertilizers were applied in strips measuring 6 by 83 feet or slightly more than 1/100 acre in area,

leaving unfertilized alleys of 2 feet in width between strips. The fertilizers were applied for the purpose of studying the effect of lime, phosphorus, and potassium on the nodulation of the different strains of nodule bacteria and on the growth of alfalfa. The fertilizer applications were made the same day the inoculated seed was planted and the materials were mixed with the soil by thorough and vigorous raking to avoid immediate contact of the fertilizers with the seed as much as possible. The treatments were made as follows:

Plat No.	Treatment	Kind of fertilizer and rate of application per acre
1	P_2O_5	400 lbs. superphosphate
2	K_2O	150 lbs. muriate of potash
3	$P_2O_5+K_2O$	400 lbs. superphosphate, 150 lbs. muriate of potash
4	Check	No fertilizers
5	Lime	3000 lbs. lime (air slacked)
6	Lime+P_2O_5	3000 lbs. lime, 400 lbs. superphosphate
7	Lime+K_2O	3000 lbs. lime, 150 lbs. muriate of potash
8	Lime+P_2O_5+K_2O	3000 lbs. lime, 400 lbs. superphosphate, 150 lbs. muriate of potash

As in the first experiment, no nurse crop was used for the alfalfa and the plantings were made during the latter part of May, broadcasting the inoculated seed at the rate of 16 pounds per acre. The amounts of inoculation used were double those recommended for field practice to avoid the possibility of not inoculating the soil sufficiently to secure abundant nodulation on the young alfalfa plants.

EXPERIMENTAL RESULTS

Since the main purpose of the first experiment was to ascertain the nodulation power of various strains of alfalfa nodule bacteria in different soil types and their adaptability to western Washington soil and climatic conditions, it was important to observe the differences in numbers of nodules produced on the roots of the young alfalfa plants due to specific strains of nodule bacteria as well as the effect of abundant nodulation on the development of the host plant. As shown by Helz, Baldwin, and Fred (5) in their work with peas, large numbers of nodules on the roots do not necessarily indicate that the host plant is greatly benefited by the nodule bacteria. Strain specificity, size, and location of nodules seem to be important factors. Erdman (2), who worked with soybeans, emphasized the importance of the size of nodules as well as the numbers.

With these factors in mind it was first intended to make an accurate check upon the number, size, and location of nodules on the roots of the young alfalfa plants as it was thought that satisfactory inoculation of these soils was rather difficult to obtain. Consequently, strain specificity in regard to number, size, and location of

nodules as well as differences in the benefit to the host plant among the 24 strains of alfalfa nodule bacteria used might be expected to be marked and significant. A preliminary examination of the roots of the young alfalfa plants in the various plats indicated that with only one exception all soil types included in this experiment were inoculated without difficulty by the large majority of strains of nodule bacteria. This observation suggested that proper inoculation in this experiment might not be as important a factor in the successful growth of alfalfa as was first thought and resulted in abandoning the initial plan of accurately counting the actual number of nodules per plant and of making careful records of their size and location. Instead, a general estimate of the numbers of nodules and careful observations regarding the size and thrift of the alfalfa on the various plats were recorded during the month of September after the fall rains, which follow the usual dry spell in summer, had taken effect.

TABLE 1.—*Nodulation by various strains of alfalfa legume bacteria cultures in different soils of western Washington in 1927.*

Plat No	Strains of bacteria	Not fertilized with P_2O_5				Fertilized with P_2O_5 in 1926		
		Soil 1*	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
1	Ma	++†	+	+	++	+++	++	+
2	W116	++++	+++	+++	+++	++++	++++	+++
3	N1	+++	+	+	++	++	+++	++
4	F	++	+++	+	+	—	++	+
5	S1	+++	—	+	+++	++	+++	+++
6	Na	++++	—	++	+++	++	+++	++
7	W31	++++	++++	++	+++	++++	++++	++
8	C1	++++	++++	++++	+++	++++	+++	++
9	H	++	+	+	++	++	+	+++
10	F1	++	++	+	++	+++	+++	++
11	U	++++	++++	+++	+++	++++	++++	+++
12	B1	+	++	+	++	++	++	++
13	W106	++++	++++	+++	+++	++++	+++	+++
14	N6	+++	++++	++	+++	—	++++	++++
15	W40	++++	++	++++	+++	++++	+++	+++
16	U1	+++	++	++	+++	+++	+++	++
17	W5	++++	—	+++	+++	+++	++++	++
18	Pn	++	+++	+	+++	++++	+++	+++
19	Pf	++++	+++	+++	+++	++++	++++	+++
20	Pa	+++	—	++++	++++	++++	++++	+++
21	He	+++	++++	++	+++	++++	+++	+++
22	O1	+++	++++	+++	+++	++++	++++	+++
23	B25	++++	++++	++	++	+++	+++	+++
24	B20	+++	++++	+	+++	+++	+++	+++
25	Check	—	—	—	—	—	+	—

*Soil 1 = Everett silt loam, Western Washington Experiment Station; 2 = Everett gravelly sandy loam, Enumclaw; 3 = Everett stony sandy loam, Kent; 4 = Everett gravelly sandy loam, Edmonds; 5 = Everett sandy loam, Carnation; 6 = Puget coarse sandy loam, Woodinville; 7 = Puget silt loam, Renton Junction.

†+ = poor; ++ = fair; +++ = good; ++++ = very good; — = no nodules.

The results of nodulation of the various strains of nodule bacteria are given in Table 1.

It may be noted that the plat located on the Everett stony sandy loam soil at Kent was not as easily inoculated as the other soils in the experiment. This happened to be a field that had been cleared recently from cut-over forest land and it is possible that this fact may have influenced the results. Three of the fields where the plats were established had been fertilized with superphosphate during the previous year, but no marked effect of this fertilization upon nodulation or growth of the alfalfa could be observed. In general, all strains of nodule bacteria used gave satisfactory results with the possible exception of strains Ma, N1, F, H, F1, and B1 which caused inferior nodulation in the majority of the soil types.

During the early part of the summer the young alfalfa on all of these plats appeared to be vigorous and thrifty, but later in the season the majority of the plats began to show the typical symptoms of yellowing and poor growth so frequently observed in new seedings in this area. No marked and consistent difference in growth or color of the alfalfa could be observed as a result of strain specificity, except on the Everett silt loam set of plats at the Western Washington Experiment Station and on the Everett gravelly, sandy loam set of plats at Enumclaw. These two soil types seemed to be slightly better adapted to alfalfa than the others, judging from the general appearance of the young alfalfa. Marked differences in height and color resulting from strain specificity of nodule bacteria were noticeable on certain plats. The alfalfa there was decidedly larger and darker in color so that the plat lines were plainly visible during the first season. Strains C1, U, W31, and W106 produced outstanding results in this respect.

The first year's results of this experiment suggested that, although certain strains of alfalfa nodule bacteria seemed to be better adapted to western Washington soil types and apparently benefited the alfalfa more than others, satisfactory inoculation in general was not difficult to obtain. Therefore, it was suspected that factors other than inoculation were also contributing to the unsatisfactory growth of alfalfa in these soil types.

The second series of plats established in the spring of 1928 on three soil types on which alfalfa was known to grow poorly and two soil types on which alfalfa had been growing successfully in only a few instances was fertilized as indicated in the experimental plan for the purpose of studying the effect of these fertilizers on the growth of alfalfa as well as their effect upon nodulation by the various strains

of nodule bacteria. As in the first experiment the roots of the young plants were examined for nodules in September and the comparative numbers estimated. The results are recorded in Table 2.

No significant difference in vigor and growth of the alfalfa was observed on any of the plats as a result of strain specificity. This may be explained by the fact that in all the fields selected for this experiment alfalfa grew very poorly. According to the work of Helz and Whiting (6), a generous application of fertilizers to the soil at planting time might be expected to have some injurious effect upon nodulation. In general, no difficulty was encountered in obtaining good inoculation in all of these soil types irrespective of treatment, with the exception of the two check plats on the Spanaway series which were less well inoculated. However, this was not due to the effect of fertilizers as these two plats were the unfertilized inoculated check plats. These two soil types are low in soil fertility and ordinarily respond well to generous applications of lime and complete fertilizers. As may be noted from the data in Table 2, the application of lime, superphosphate, and sulfate of potash, either singly or in combinations, apparently caused some increase in nodulation on the alfalfa roots in these two soils, while in the Everett sandy loam, the Puget sandy loam, and the Whatcom silt loam soils the application of lime alone and lime with or without superphosphate or sulfate of potash was decidedly effective in causing increased nodulation. This beneficial effect of lime on nodulation is in accord with the results of Fred, *et al.* (3), Alway and Nesom (1), and others.

The effect of superphosphate and sulfate of potash at the rate applied in this experiment, although seemingly beneficial to nodule production in the two soil types of the Spanaway series, was not in evidence in the appearance or growth of the alfalfa on these soils nor on any of the other three soils used in this experiment. Subsequent fertilizer experiments with cereal and hay crops on these five soil types have given good responses from the use of nitrogen and phosphate fertilizers, but more uncertain results have been obtained with potassium fertilizers applied singly or in combination with either nitrogen or phosphate fertilizers. It would seem that if the addition of phosphorus to these soils is beneficial for cereals and grasses it might be expected to benefit alfalfa, especially when the latter is well inoculated and therefore should be well supplied with nitrogen taken from the air.

The results obtained correspond somewhat with those of Alway and Nesom (1) who found very little beneficial effect on alfalfa from applications of phosphate and potash fertilizers. It is not likely

TABLE 2.—*Nodulation by various strains of alfalfa legume bacteria cultures in different soils treated with various combinations of commercial fertilizers in 1928.*

Plat No.	Strains of bacteria	Soil 1*	Soil 2	Soil 3	Soil 4	Soil 5	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
				P_2O_5					K_2O		
1	Check	—†	—	—	—	—	—	—	—	—	—
2	N6	+++	++	+++	+++	++++	++	+++	+++	+++	++++
3	W31	+++	+++	+++	+++	++++	+++	++	+++	+++	++++
4	Na	++	++	+++	+++	++++	++	++	+++	+++	++++
5	C1	++	++	+++	+++	++++	+++	++	+++	+++	++++
6	U	+++	++	+++	+++	++++	+++	+++	+++	+++	++++
7	W106	+++	+++	+++	+++	++++	+++	+++	+++	+++	++++
8	H	++	++	+++	+++	++++	+++	++	+++	+++	++++
9	Pa	+++	++	+++	+++	++++	+++	+++	+++	+++	++++
10	W	+++	+++	+++	+++	++++	+++	+++	+++	+++	++++
11	S1	++	+++	+++	+++	++++	++	++	+++	+++	++++
12	Mc	++	++	+++	+++	++++	++	++	+++	+++	++++
				$P_2O_5+K_2O$					Check		
1	Check	—	—	—	—	—	—	—	—	+	—
2	N6	+++	+++	+++	+++	++++	+++	++	+++	+++	++++
3	W31	+++	+++	+++	+++	++++	++	++	+++	+++	+++
4	Na	++	++	+++	+++	++++	+++	++	+++	+++	++++
5	C1	++	+++	+++	+++	++++	+	+	+++	+++	+++
6	U	+++	+++	+++	+++	++++	+	+	+++	+++	+++
7	W106	+++	++	+++	+++	++++	+++	+	+++	+++	++
8	H	+++	++	+++	+++	++++	+	+	++	++	++
9	Pa	+++	+++	+++	+++	++++	++	+	++	++	++
10	W	+++	+++	+++	+++	++++	+++	++	+++	+++	++
11	S1	++	++	+++	+++	++++	+	++	++	++	+
12	Mc	++	++	+++	+++	++++	+	+	++	++	+

		Lime					$CaCO_3+P_2O_5$				
1	Check	—	—	—	—	—	—	—	—	—	—
2	N6	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
3	W31	+++	+++	++++	++++	++++	+++	+++	++++	++++	++++
4	Na	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
5	C1	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
6	U	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
7	W106	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
8	H	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
9	Pa	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
10	W	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
11	S1	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
12	Mc	+++	++	++++	++++	++++	+++	+++	++++	++++	++++
		$CaCO_3+K_2O$					$CaCO_3+P_2O_5+K_2O$				
1	Check	—	—	—	—	—	—	—	—	—	—
2	N6	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++
3	W31	+++	+++	++++	++++	++++	++++	++++	++++	++++	++++
4	Na	+++	+++	++++	++++	++++	++++	++++	++++	++++	++++
5	C1	+++	+++	++++	++++	++++	++++	++++	++++	++++	++++
6	U	+++	+++	++++	++++	++++	++++	++++	++++	++++	++++
7	W106	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++
8	H	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++
9	Pa	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++
10	W	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++
11	S1	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++
12	Mc	+++	+++	++++	++++	++++	+++	++++	++++	++++	++++

*Soil 1 = Spanaway medium sand, Olympia; 2 = Spanaway gravelly sandy loam, Rochester; 3 = Everett sandy loam (gravelly phase), Enumclaw; 4 = Puget sandy loam, Kent; 5 = Whatcom silt loam, Bellingham.

†+ = poor; ++ = fair; +++ = good; ++++ = very good; — = no nodules.

that the soil reaction was very unfavorable as it was not excessively acid and nodulation was very satisfactory.

According to Sewell and Gainey (8), a soil reaction within the range of pH 4.5 to 7.0 is a minor factor in affecting growth of alfalfa if all the needed nutrients are supplied. The reaction of the soils on which these plats were located was determined by means of the quinhydrone electrode and, as shown in Table 3, was well within the above limits. The drainage and the physical condition of the soils were good. Assuming that nodulation, reaction, drainage, and physical condition were not limiting factors, the cause of the poor growth of alfalfa on these soils must be sought in the supply of nutrients.

TABLE 3.—*Reaction of soils of the fertilized plats before the application of fertilizers.*

Plat No.	Soil type and location	pH
1	Spanaway medium sand, Olympia	5.3
2	Spanaway gravelly sandy loam, Rochester	5.4
3	Everett sandy loam (gravelly phase), Enumclaw	5.9
4	Puget sandy loam, Kent	6.1
5	Whatcom silt loam, Bellingham	6.5

Apparently the relatively generous application of phosphate and potash fertilizers at planting time either did not become available to the young alfalfa plants or did not supply all the nutrients necessary for vigorous growth. In subsequent fertilizer plat experiments with other crops in this area occasional soil types have been found which failed to respond satisfactorily to a single application of fertilizers such as made in this experiment but gave much better results following a second or third application in successive years. Unfortunately, the fertilizer treatments on the alfalfa plats were not repeated the following year, but the plats were kept under observation for possible residual effects of the various fertilizers. In 1929 all the plats were visited except those on the Puget series which had been plowed. The four remaining sets of plats showed the yellowing and stunted growth conditions typical of the second year's growth of alfalfa on many of the unfertile soil types of western Washington and no residual effect of the various fertilizers applied during the previous year were observable. Inoculation was still plentiful. In certain cases alfalfa plants that were so stunted and yellow that they were about to die were abundantly supplied with nodules on their roots and it seemed as though the nodule bacteria on those particular plants were distinctly parasitic instead of symbiotic.

The two plats showing distinct effects of strain specificity in 1927 were kept under observation during 1928 and 1929. On the plats located on Everett gravelly sandy loam at Enumclaw, the alfalfa showed typical yellowing and poor vigor in 1928 and the differences due to specific strains of alfalfa nodule bacteria were no longer visible. On the Everett silt loam plats at the Western Washington Experiment Station the effects of specific strains were still evident in 1928 and 1929, but even in this soil the alfalfa grew unsatisfactorily and could hardly be called a success.

The data obtained in these experiments suggest that thorough inoculation of the soil with alfalfa nodule bacteria, adequate drainage, good physical condition, and proper reaction of the soil, although very important factors in growing alfalfa successfully, are by no means the only ones to be considered in growing alfalfa on many of the soil types of the humid sections of western Washington. Soil fertility also is deserving of careful consideration, particularly in those soils on which alfalfa does not grow readily. After all, alfalfa is a crop which draws heavily upon the mineral plant food of the soil and if one or more of the mineral plant food elements are deficient, alfalfa, like any other crop, cannot thrive. This crop requires a fertile soil with respect to mineral plant food. The results of the fertilized alfalfa plats furnish some evidence to show that an abundant supply of available mineral plant food may not always be realized by means of a single application of plentiful amounts of soluble commercial fertilizers to the soil. The soil itself is a powerful medium in controlling the absorption or the release of the mineral plant food applied to it in soluble form. To grow alfalfa successfully in many of the soils in western Washington where it grows with difficulty now, it will be necessary to give first consideration to a practical plan of building up soil fertility. A general survey of the different sections where attempts have been made to grow alfalfa on the various soil types of the soil series included in these experiments indicates that the majority of the good stands of alfalfa have been secured and maintained on fields on which barnyard manure had been applied frequently before the alfalfa was planted and was still being applied on the alfalfa field.

An increase in active organic matter may be necessary to stimulate the biological and chemical processes of these soils, thereby liberating more mineral plant food in available forms. Generous applications of barnyard manure or green manures in addition to the liberal use of commercial or mineral fertilizers may prove to be the most satisfactory and most rapid means of building up the soil fertility,

which, according to the results of the foregoing experiments, is essential before it can be expected to grow alfalfa successfully on many of the soil types in western Washington.

SUMMARY

Experiments were conducted in two series of field plats in western Washington to ascertain the inoculating and nitrogen-fixing power of various strains of alfalfa nodule bacteria, their adaptability to a number of soil types in this area, and the effect of various fertilizer applications on nodulation and on the growth of alfalfa.

The results of these experiments indicated with few exceptions that seed inoculated according to directions given for the various cultures and planted without a nurse crop at the rate of seeding customary in field practice resulted in satisfactory inoculation of the alfalfa with the large majority of strains of nodule bacteria tested in the various soil types included in these field plats.

Although a good stand was secured in all cases, the alfalfa on all of the plats failed to grow satisfactorily toward the end of the first growing season and during the two following growing seasons. The application of lime and commercial fertilizers had no marked beneficial effect upon the growth of the alfalfa in spite of the fact that lime applied alone or in combination with commercial fertilizers caused marked increases in nodulation in the majority of the field plats.

Differences in nodulation caused by the various strains of alfalfa nodule bacteria were not sufficiently outstanding to be significant, but marked differences in the first year's growth and thrift of alfalfa were observed in two soil types as a result of bacterial strain specificity. However, this increase in growth and thrift was not sufficiently great or lasting to make the alfalfa on these plats a success in its second and third years.

Soil inoculation with nodule bacteria, soil drainage and physical condition, and soil reaction, although somewhat acid in all plats, did not prove to be limiting factors in the growth of alfalfa. Therefore, it was apparent that the available mineral plant food in these soils probably was deficient for successful growth of alfalfa and was not restored by a single but generous application of commercial fertilizers.

Repeated fertilization with barnyard manure or green manure crops in addition to liberal applications of commercial fertilizers is suggested as a means of building up the available mineral plant food supply of these soils before seeding them to alfalfa.

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AVAILABILITY OF ROCK PHOSPHATE AS INDICATED BY PHOSPHORUS ASSIMILATION OF PLANTS[1]

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It is evident from numerous investigations pertaining to availability of phosphates that the various solvents generally employed for this purpose do not afford satisfactory indications of effectiveness of different sources of phosphorus for crop production. As the availability of phosphates cannot be measured except by arbitrary or empirical procedures, the condition of phosphates incorporated with soil is not known and is difficult to define except as it is considered from the viewpoint of crop response and utilization by plants. It is true that the practice of determining solubility of phosphorus in certain fertilizer materials furnishes a comparative measure of their probable availability and effectiveness, but unfortunately solubility and availability are not synonymous.

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It is the opinion of some investigators that more satisfactory information can be obtained through the medium of the assimilating power of plants. During the progress of investigations of phosphates, the plant method supplemented other procedures employed for measuring the available supply in soils and mineral phosphates. Some results obtained pertaining more specifically to the influence of acid and limed soil, degree of fineness, and rate of application on the plant's utilization of phosphorus from rock phosphate are presented in this paper. Information regarding the possibilities and limitations of procedures based on plant composition for measuring availability of phosphorus supply in soils is also furnished by these experiments.

PHOSPHORUS FIELD-TREATED SOILS

One of the fertility experiments at the Ohio Experiment Station provides for comparison of the effectiveness of rock phosphate with superphosphate as sources of phosphorus. Certain plats included in this experiment, designated as the lime and floats test, have had additions of rock phosphate since 1897. Other treatments on these plats have been lime, manure, and superphosphate. Bulletin 381 of the Ohio Experiment Station gives the plat treatment of soils used in these pot culture tests. The phosphorus content of plants grown in pot tests with soils from several differently treated plats of this field experiment are presented in Table 1.

TABLE 1.—*Phosphorus assimilation from field-treated soils.*

Plat No.	Field treatment per acre for 3-year period, lime and floats plats	Phosphorus in plants	
		Buckwheat	Clover
		%	%
1*	None	0.141	0.130
5	Manure, 8 tons; lime, 2,000 lbs	0.176	0.227
12	Rock phosphate, 1,000 lbs.; manure, 8 tons	0.420	0.269
18	Rock phosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs.	0.196	0.200
24	Rock phosphate, 320 lbs.; muriate potash, 40 lbs.	0.282	0.192
21	Superphosphate, 320 lbs.; muriate potash, 40 lbs.	0.228	0.218
17	Superphosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs	0.181	0.212

*Composite soil from untreated plats.

It will be observed that buckwheat readily assimilated phosphorus from soil that has had an application of 1,000 pounds of rock phosphate per acre each 3-year period for 30 years. Less phosphorus was obtained by plants from the smaller application of 320 pounds of rock phosphate. This amount, however, was approximately the same as was assimilated from superphosphate applied at the same rate. The

phosphorus content of clover succeeding buckwheat in this series does not exhibit the wide variations due to soil treatment that occur in buckwheat plants.

In a more extended series of tests with soils that had field treatment with rock phosphate and superphosphate, successive crops of buckwheat, clover, and soybeans were grown in 25-pound portions of soil. Additions of rock phosphate, limestone, and nitrogen carriers were made to certain portions of these field-treated soils as designated in Table 2 stating the phosphorus assimilation by the three crops.

Phosphorus residual from field applications of phosphates was reflected rather consistently by increased percentages of phosphorus in buckwheat, but a following crop of clover and of soybeans after clover did not show as consistent indications of variations in the phosphorus supply. With rock phosphate additions to soils in pots just previous to planting buckwheat, the effect on phosphorus assimilation was similar to that resulting from the more remote field applications. Available nitrogen supplied with rock phosphate in some instances appreciably increased the utilization of phosphorus from this source. The phosphorus content of plants grown in soil with neither field nor pot additions of phosphates indicates that the capacity of clover and soybeans exceeded that of buckwheat to utilize the natural phosphorus supply of the soil. Although the phosphorus content of plants in the series just described corresponds rather closely with the phosphate addition, the indications furnished by plants are not in accord with crop yields on these soils, as is shown by crop increases stated in Table 3.

Considering the soil treatments in relation to crop response, the question may be raised as to whether crop production on certain plats of the lime and rock phosphate experiment is not limited by other factors than the phosphorus supply. Crop increases where lime was applied and where manure furnished nitrogen are evidence of this. A comparison of plant composition and crop yields from soil treatment with rock phosphate at the rate of 1,000 pounds per acre supplemented with manure and from treatment with 1,000 pounds of lime with the same amount of manure shows a larger amount of phosphorus taken up by buckwheat from rock phosphate-treated soil, but lime-treated soil produced decidedly larger crop increases except in the case of oats.

It is recognized that buckwheat is a gross feeder on soil minerals, including phosphates, and that the capacity of different plants to utilize phosphates is decidedly variable. In these experiments buckwheat has been a satisfactory crop for insurance of good growth of

TABLE 2.—*Phosphorus assimilation by buckwheat, clover, and soybeans.*

Plat No.	Field treatment per acre for 3-year period, lime and floats plats	Pot additions*	Plant weight in grams	Phosphorus content %	Phosphorus removal in mg
		Buckwheat			
1†	None	None	26	0.142	36
		Limestone	29	0.127	37
		Rock phosphate	33	0.406	134
		Rock phosphate, limestone	27	0.143	38
		Rock phosphate, nitrate soda	34	0.473	160
5	Lime, 2,000 lbs.; manure, 8 tons	Rock phosphate	31	0.288	88
		Rock phosphate, sulfate ammonia	41	0.410	169
12	Rock phosphate, 1,000 lbs.; manure, 8 tons	None	24	0.420	86
		Limestone, muriate potash, nitrate soda	25	0.197	50
18	Rock phosphate, 320 lbs., lime, 1,000 lbs., muriate potash, 40 lbs.	None	30	0.205	62
		Nitrate soda	34	0.213	72
24	Rock phosphate, 320 lbs.; muriate potash, 40 lbs	None	26	0.297	77
		Limestone	30	0.261	78
17	Superphosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs	None	29	0.172	50
		Rock phosphate	32	0.342	109
		Rock phosphate, nitrate soda	35	0.435	152

Clover

1†	None	None	14	0.180	25
		Limestone	25	0.234	59
		Rock phosphate	27	0.233	63
		Rock phosphate, limestone	24	0.240	58
		Rock phosphate, nitrate soda	30	0.290	87
5	Lime, 2,000 lbs.; manure, 8 tons	Rock phosphate	22	0.289	64
		Rock phosphate, sulfate ammonia	37	0.284	105
12	Rock phosphate, 1,000 lbs.; manure, 8 tons	None	23	0.304	70
		Limestone, muriate potash, nitrate soda	23	0.282	65
18	Rock phosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs.	None	20	0.255	51
		Nitrate soda	20	0.325	65
24	Rock phosphate, 320 lbs.; muriate potash, 40 lbs	None	28	0.299	84
		Limestone	20	0.356	71
17	Superphosphate, 320 lbs.; lime, 1,000 lbs; muriate potash, 40 lbs.	None	20	0.262	52
		Rock phosphate	20	0.272	54
		Rock phosphate, nitrate soda	20	0.359	66

*Pot additions at following rates per acre area basis: Rock phosphate, 800 lbs.; limestone, 100-mesh, 6,000 lbs.; nitrogen carriers' 150 lbs.; muriate potash, 40 lbs.

†Composite soil from untreated plats.

TABLE 2.—*Continued.*

Plat No.	Field treatment per acre for 3-year period, lime and floats plats	Pot additions*	Plant weight in grams	Phosphorus content %	Phosphorus removal in mg
		Soybeans			
1†	None	None	15	0.302	45
		Limestone	15	0.304	45
		Rock phosphate	14	0.264	37
		Rock phosphate, limestone	15	0.336	50
		Rock phosphate, nitrate soda	15	0.255	38
5	Lime, 2,000 lbs.; manure, 8 tons	Rock phosphate	15	0.270	41
		Rock phosphate, sulfate ammonia	15	0.400	60
12	Rock phosphate, 1,000 lbs.; manure, 8 tons	None	15	0.336	50
		Limestone, muriate potash, nitrate soda	15	0.360	54
18	Rock phosphate, 320 lbs.; muriate potash, 40 lbs.; lime, 1,000 lbs.	None	15	0.256	38
		Nitrate soda	13	0.462	60
24	Rock phosphate, 320 lbs.; muriate potash, 40 lbs.	None	14	0.256	36
		Limestone	15	0.357	54
17	Superphosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs.	None	15	0.362	54
		Rock phosphate	15	0.380	57
		Rock phosphate, nitrate soda	15	0.430	64

*Pot additions at following rates per acre area basis: Rock phosphate, 800 lbs.; limestone, 100-mesh, 6,000 lbs.; nitrogen carriers, 150 lbs.; muriate potash, 40 lbs.

†Composite soil from untreated plats.

TABLE 3.—*Comparison of crop increases on lime and floats plats with yield and phosphorus removal of buckwheat in pot culture.*

Plat No.	Field treatment per acre per 3-year rotation, lime and floats plats	Plant weight in grams	Phosphorus in plant %	Crop increases per acre			Value of increase
				Corn, bu.	Oats, bu.	Clover, lbs.	
1*	None	26	0.142	—	—	—	—
26	Manure, 8 tons	26	0.137	19.84	7.71	934	$26.40
3	Manure, 8 tons; lime, 1,000 lbs	28	0.150	25.84	10.37	2,045	41.48
12	Rock phosphate, 1,000 lbs.; manure, 8 tons	24	0.420	20.08	13.50	1,083	30.90
24	Rock phosphate, 320 lbs.; muriate potash, 40 lbs	26	0.297	10.24	4.21	215	11.79
18	Rock phosphate, 320 lbs.; muriate potash, 40 lbs.; lime, 1,000 lbs.	30	0.205	16.65	8.65	1,555	29.00
21	Superphosphate, 320 lbs.; muriate potash, 40 lbs	25	0.228	14.16	5.54	318	16.35
17	Superphosphate, 320 lbs.; muriate potash, 40 lbs.; lime, 1,000 lbs	29	0.172	21.59	12.03	1,816	36.71

*Composite soil from untreated plats.

plants under the adverse temperature conditions often prevailing in the glass houses available for vegetable tests. Table 4 shows the phosphorus taken up from rock phosphate, di-calcium phosphate, and sodium phosphate by wheat plants and by two preceding crops of buckwheat.

TABLE 4. - *Comparative assimilation of phosphorus by buckwheat and wheat.*

Phosphate additions in pounds per acre	Phosphorus in plants		
	Buckwheat		Wheat after buckwheat %
	First crop %	Second crop %	
None .	0.108	0.164	0.142
Di-sodium phosphate, 200	0.475	0.540	0.504
Di-calcium phosphate, 200	0.492	0.565	0.718
Rock phosphate, 800 .	0.457	0.508	0.234

Compared with buckwheat, the wheat plants had less power to utilize rock phosphate but readily utilized phosphorus from di-calcium and sodium phosphates.

EFFECT OF SOIL REACTION

The general conception of available soil nutrients has been that minerals must be made soluble by action of various soil agencies before plants can utilize them. However, there are other opinions regarding the factors affecting the feeding power of plants for nutrients. One of the theories proposed is that of Comber (3)[3] who states that the assumption that minerals must be in solution is unjustified. He considers that colloids play an important part by being directly absorbed by plants through the union of roots with minerals of the soil, forming a one-phase system by cementing together the colloidal coating of roots and the colloidal coating of soil particles. This permits of direct dissolution from particular particles by the cell sap. So far no conclusive evidence has been obtained that colloidal action of this nature is the important factor influencing availability of insoluble phosphates.

The evidence from investigations of this phase of plant nutrition appears to support the conclusion that plants obtain mineral nutrients from the soil solution and that effectiveness of phosphates for crop production depends to a considerable extent on the rate of solution. Assuming that solution is primarily essential and that carbon dioxide

[3]Reference by number is to "Literature Cited," p. 122.

is the principal solvent, the reaction between tri-calcium phosphate and carbonic acid may be considered to proceed as follows:

$$Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftarrows Ca_2H_2(PO_4)_2 + Ca(HCO_3)_2$$

If this conception is correct, then the effectiveness of insoluble phosphates will depend on soil conditions affecting solubility, among which is supply or absence of calcium carbonate. If calcium carbonate is present in sufficient quantity, no appreciable amount of di-calcium phosphate will be produced and the availability of the phosphate will be depressed.

Some of the numerous field tests with phosphates under different conditions have indicated that rock phosphate is more effective on acid soil, while other tests show that better returns were obtained on limed soil. One of the tests on acid soil at the Rhode Island Experiment Station (5) gave the following results:

Soil treatment	Total value of increase per acre for 20 years	
	Limed soil	Unlimed soil
Raw phosphate	$269	$358
Superphosphate	486	440

Crop increases on Ohio Experiment Station plats (9) treated with 320 pounds of rock phosphate and superphosphate, both supplemented with muriate of potash on limed and unlimed soil, are as follows:

Soil treatment	Increases from phosphates on limed and acid soil		
	Corn, bu.	Oats, bu.	Clover, lbs.
Rock phosphate limed soil	8.42	2.14	272
Rock phosphate acid soil	10.24	4.21	215
Superphosphate limed soil	13.16	5.52	553
Superphosphate acid soil	14.16	5.54	318

Assuming that lime has had the same proportionate effect in combination with phosphate as when used separately, increases for phosphates on limed soil were obtained by deducting increases produced by lime alone. Increases of corn and oats indicate that rock phosphate was more effective on acid soil. This is in accord with indications furnished by phosphorus taken up by buckwheat plants from acid and limed soil.

Data pertaining to the utilization by plants of phosphates from acid and limed soil are presented in Table 5. Plants were grown in soils that had field treatment with lime and with phosphates, and in these same field-treated soils with further additions of these materials, thus affording a double comparison of effect of acid and basic soil conditions on availability of phosphates for plants. There was an increased phosphorus content in plants grown in soil with phosphates

TABLE 5.—*Influence of acid and limed soil on phosphorus assimilation by buckwheat.*

Plat No.	Field treatment per acre, 3-year period, lime and floats plats	pH value soils	Additions to soil in pots*	Plant weight in grams	Phosphorus in plants %
1	None	5.4	None	27	0.146
			Limestone	36	0.152
			Rock phosphate	30	0.450
			Rock phosphate, limestone	29	0.271
			Superphosphate	29	0.342
			Superphosphate, limestone	36	0.330
14	Lime, 1,000 lbs	7.1	None	22	0.160
			Rock phosphate	38	0.380
			Superphosphate	39	0.294
5	Lime, 2,000 lbs.; manure, 8 tons	7.9	None	37	0.189
			Rock phosphate	39	0.365
			Superphosphate	44	0.286
12	Rock phosphate, 1,000 lbs.; manure, 8 tons	5.4	None	24	0.361
			Limestone	25	0.197
24	Rock phosphate, 320 lbs.; muriate potash, 40 lbs	5.3	None	26	0.297
18	Rock phosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs	7.0	None	30	0.205
21	Superphosphate, 320 lbs.; muriate potash, 40 lbs	5.3	None	25	0.228
17	Superphosphate, 320 lbs.; lime, 1,000 lbs.; muriate potash, 40 lbs	7.0	None	31	0.180

*Additions to soil in pots were at the following rates per acre: Rock phosphate, 800 lbs.; superphosphate, 400 lbs.; limestone, 100-mesh, 6,000 lbs.

supplied by field treatment. The most marked increase of phosphorus in the plants of this series occurred with the addition of rock phosphate to the soil in pots.

With the reaction of the soil changed by calcium carbonate supplied by 100-mesh limestone, phosphorus assimilation by plants indicated a decreased availability, which was more pronounced with rock phosphate than superphosphate following direct addition of limestone to soils in pots. The smaller reduction in the amount of phosphorus obtained by plants from phosphates added to previously limed field soil indicates that remoteness of liming from phosphate treatment may influence the extent to which availability of rock phosphate is decreased by lime. The only direct comparison afforded by the field-treated soils regarding effectiveness of phosphates on acid and basic soils is from the 320 pounds per acre rate of application of rock phosphate and superphosphate. The pH value of soil with no lime treatment was 5.3 and that of the limed soil 7.

Limestone addition to pots caused a decrease in the amount of phosphorus taken up by plants from soil having previous field applications of rock phosphate. This also occurred when field soil had been limed and phosphate was added to the pots. It will be noted that phosphorus secured by plants from soil with no phosphate treatment was not diminished by the addition of limestone. The addition of 2,000 pounds of lime each 3-year period of the rotation has raised the pH value of soil from 5.4 to 7.9. With the 1,000-pound application of lime the soil reaction is approximately pH 7. Rock phosphate or superphosphate additions have not appreciably changed the reaction. Limestone addition to pots was at a rate to bring the soil reaction to pH 7. The effect of liming on phosphorus assimilation is also shown by the results for buckwheat, clover, and soybeans previously stated in Table 2. There was a decreased content of phosphorus in buckwheat grown soon after the soil treatment, while there was a general tendency for an increased assimilation by clover grown 4 months after the soil treatment and by soybeans after 7 months had elapsed. The longer period intervening between soil treatment with limestone and the growing of clover and soybeans may have been a factor affecting the influence of lime on phosphorus assimilation by these crops as compared with that of buckwheat.

Roberts (8) has reported results of extensive experiments with phosphates. These tests show that on some soils rock phosphate appears to be as effective as superphosphate on limed soil. In other cases lime has depressed the effectiveness of rock phosphate. He suggests that addition of lime far enough in advance of the use of

rock phosphate to permit of the disappearance of calcium carbonate might be a solution of the difficulty when lime interferes with the availability of rock phosphate.

LEGUME-REACTION EXPERIMENT

Further indications regarding the effect of acid and basic soil conditions on phosphorus utilization were obtained from plants grown in soil from plats included in a legume-reaction project of the Agronomy Department. Field applications of aluminum sulfate were made to adjust the soil reaction to pH 4.5. Seven tons of limestone per acre were applied where the reaction is to be maintained at pH 8. The south half of all plats included in this project has an application of superphosphate at the rate of 250 pounds per acre for corn and 500 pounds for small grain.

Previous to growing plants in the soils described, rock phosphate and calcium carbonate were added at the rates per acre stated in Table 6, giving data for phosphorus in plants. It will be noted that plants obtained an increased amount of phosphorus from soil with field treatment of superphosphate. This increase of phosphorus in plants grown in soil with reaction of pH 4.5 was 72% over that of plants grown in non-phosphated soil, as compared with a smaller increase of 33% from superphosphate-treated soil with pH value raised to pH 8 by field application of limestone More phosphorus, however, was assimilated by plants from the natural phosphorus supply of this soil with the higher pH value. Utilization of phosphorus by the first crop of buckwheat from rock phosphate added to the limed soil was not affected by increased basicity, although this condition appreciably decreased the amount obtained by a second crop of buckwheat and succeeding soybean crop.

PHOSPHORUS-CALCIUM RELATION

The theory has been proposed that plants obtain calcium as well as phosphorus from rock phosphate. According to Chirkov (2), plants that readily assimilate calcium ions can utilize slightly soluble phosphates.

Truog (10) elaborated this idea in presenting a theory regarding the feeding power of plants. His hypothesis was that plants with a relatively high calcium content have a high feeding capacity for insoluble phosphates. This was explained by laws of mass action and chemical equilibrium, assuming that phosphorus of rock phosphate is made available according to reaction between rock phosphate and carbonic acid, producing di-calcium phosphate. In this reaction

TABLE 6.—*Phosphorus assimilation from soils of legume-reaction project plats.*

Soil reaction and field treatment	Pot additions*	First buckwheat crop			Second buckwheat crop			Soybeans			pH value of soil at end of experiment
		Plant weight in grams	Phosphorus content %	Phosphorus removal in mg	Plant weight in grams	Phosphorus content %	Phosphorus removal in mg	Plant weight in grams	Phosphorus content %	Phosphorus removal in mg	
pH 4.5, north....	None	23	0.156	36	29	0.101	29	14	0.196	27	5.4
	Calcium carbonate	23	0.182	42	22	0.094	21	14	0.217	30	7.3
	Rock phosphate	29	0.447	130	37	0.257	95	16	0.216	35	5.4
pH 4.5, south, superphosphate†	None	23	0.269	62	29	0.143	41	19	0.295	56	5.6
	Calcium carbonate	26	0.272	61	34	0.134	46	19	0.231	44	7.2
pH 8, north.....	None	27	0.192	52	33	0.087	29	24	0.147	35	7.9
	Calcium carbonate	40	0.206	82	35	0.092	32	23	0.136	31	8.1
	Rock phosphate	28	0.432	121	33	0.177	58	27	0.141	38	7.8
pH 8, south,..... superphosphate	None	28	0.256	72	34	0.120	41	28	0.156	44	7.9
	Calcium carbonate	26	0.260	68	33	0.126	42	27	0.154	42	8.1

*Additions to pots at the following rates per acre: Rock phosphate, 800 lbs.; calcium carbonate, 6,000 lbs.
†Superphosphate 250 lbs. on corn, 500 lbs. on small grain.

equilibrium is attained when no di-calcium phosphate or calcium bicarbonate is removed from solution. Plants that remove considerable calcium will enable the reaction to proceed further than when a smaller amount is removed. Therefore, according to this theory, the feeding power of a plant for an insoluble phosphate depends upon two conditions, *viz.*, the solubility of phosphate in carbonic acid solution, and whether plants remove from solution the products of the reaction in proper proportion to allow the solubility reaction to continue indefinitely.

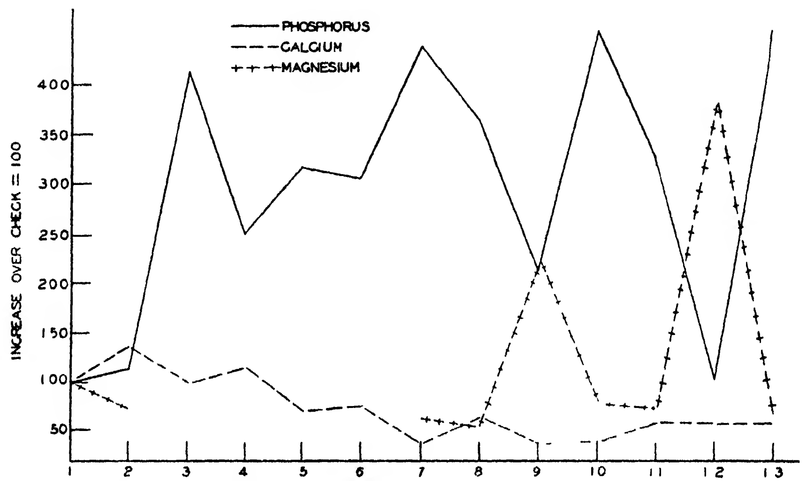

FIG. 1.—Showing influence of soil treatment on phosphorus, calcium, and magnesium assimilation by plants Numbers at bottom of graph designate the soil treatment as follows: 1. None; 2. calcium carbonate, 3. rock phosphate; 4. rock phosphate, calcium carbonate; 5. superphosphate; 6. superphosphate, calcium carbonate; 7 di-sodium phosphate, 8. di-sodium phosphate, calcium carbonate; 9. di-sodium phosphate, magnesium carbonate; 10. di-magnesium phosphate, 11. di-magnesium phosphate, calcium carbonate; 12. magnesium carbonate, and 13 di-calcium phosphate.

Bartholomew (1), in a study of the unavailability of rock phosphate for crops, found no definite relation between the calcium-phosphorus ratio in plants and their ability to feed on rock phosphate. Lieb (7) found that the calcium-phosphorus ratio fluctuates more in plants grown in pots than in field-grown plants. He states that specific soil characteristics, including absorption capacity, buffer action, and water supply have an important influence on the ash content of plants.

The phosphorus and calcium content of buckwheat plants grown with different conditions of soil treatment has furnished some interesting results regarding the phosphorus-calcium ratio. Phosphorus was

supplied by rock phosphate, superphosphate, and di-phosphates of sodium, magnesium, and calcium. Calcium and magnesium were also added as carbonates. The results obtained in this work are stated in Table 7 and graphically represented in Fig. 1.

TABLE 7.—*Phosphorus, calcium, and magnesium in plants.*

Soil treatment	Plant content			Phosphorus-calcium ratio
	Phosphorus %	Calcium %	Magnesium %	
None	0.108	1.96	0.863	1 : 18
Calcium carbonate	0.121	2.70	0.636	1 : 22
Rock phosphate	0.450	1.99	——	1 : 4
Rock phosphate, calcium carbonate	0.271	2.27	——	1 : 8.4
Superphosphate	0.342	1.39	——	1 : 4
Superphosphate, calcium carbonate	0.330	1.47	——	1 : 4
Di-sodium phosphate	0.475	0.75	0.543	1 : 1.6
Di-sodium phosphate, calcium carbonate	0.395	1.27	0.461	1 : 3.2
Di-sodium phosphate, magnesium carbonate	0.229	0.77	1.911	1 : 3.4
Di-magnesium phosphate	0.494	0.78	0.693	1 : 1.5
Di-magnesium phosphate, calcium carbonate	0.352	1.16	0.609	1 : 3.3
Magnesium carbonate	0.110	1.14	3.287	1 : 1.3
Di-calcium phosphate	0.492	1.16	0.537	1 : 2.4

Calcium was readily assimilated from calcium carbonate where this was the only addition and also where this treatment supplemented rock phosphate. No increase of calcium over that obtained from untreated soil resulted from supplying calcium carbonate in combination with superphosphate or with sodium and magnesium phosphates, although the calcium content was considerably more than was found in plants grown in soil with addition of either sodium or magnesium phosphate only. For some reason calcium assimilation from soil with sodium or magnesium phosphate treatment was decidedly less than that of plants grown under other conditions of treatment.

It is evident that plants had the capacity to assimilate a large amount of magnesium from soil supplied with magnesium carbonate. In fact, the increased content of magnesium was much larger than that of calcium in plants from soil supplied with calcium carbonate. Plants did not use an appreciably increased amount of magnesium supplied by magnesium phosphate, although phosphorus from this source was freely utilized. Apparently, the calcium of rock phosphate or di-calcium phosphate was not utilized, as no increased calcium content of plants accompanied the larger amounts of phosphorus readily secured from these sources.

The greatly increased assimilation of calcium and magnesium from carbonates and the fact that considerable amounts of phosphorus were obtained by plants from rock phosphate and calcium and magnesium phosphates with no accompanying increases of calcium or magnesium indicate that buckwheat was a heavy consumer of these base elements but exercised a selective absorption capacity in obtaining them. The larger amount of calcium furnished by calcium carbonate, as compared with the smaller amount supplied by rock phosphate and di-calcium phosphate, may have accentuated the increases of calcium obtained from this supply by plants.

The relations between phosphorus and calcium in buckwheat plants grown under different conditions of soil treatment in these experiments do not furnish evidence that utilization of phosphorus from rock phosphate is determined by the plant's capacity to obtain calcium from the same source.

FINENESS OF ROCK PHOSPHATE

The unsatisfactory showing made by rock phosphate in comparison with other phosphorus carriers in some of the earlier field tests may have been due partly to the fact that the material was not ground sufficiently fine. A more finely ground rock phosphate has recently been placed on the market. Jordan (6) made separations of Florida ground phosphate and reported that degree of fineness increased availability. Conner and Adams (4) compared commercial, finely ground, raw Tennessee phosphate with the same material reground in a ball mill. The weights of plants in pot tests showed that the reground phosphate was 7.7% more effective than the commercial phosphate. It is generally considered that fineness of fertilizer materials is of importance, as fineness of division facilitates distribution and increases the surface exposed to action of solvent agencies in the soil.

TABLE 8.—*Effect of fineness of rock phosphate on phosphorus utilization.*

Additions at rate of 800 lbs. per acre	Finer than		Phosphorus in plants	
	100-mesh %	200-mesh %	Buckwheat %	Clover %
None	—	—	0.141	0.130
Rock phosphate	75	50	0.321	0.187
Rock phosphate	91	65	0.417	0.222
Rock phosphate	100	90	0.427	0.241

Indications of the plant's capacity to utilize phosphates of different degrees of fineness were obtained from the phosphorus content of plants. In one experiment plants were grown in 25 pounds of soil

with additions of three rock phosphate products having percentages of material finer than 100-mesh and 200-mesh as stated in Table 8 below. In this test clover followed buckwheat in the same soil with one addition of rock phosphate at the rate of 800 pounds per acre.

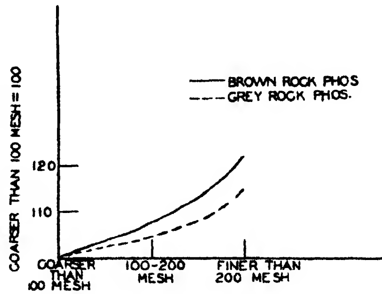

FIG. 2.—Showing effect of fineness of rock phosphate on phosphorus utilization by plants.

Although the plants grown in this series obtained appreciable amounts of phosphorus from the three rock phosphates compared, somewhat more was assimilated from the more finely ground product. The smaller amount in clover plants following buckwheat may be due to removal of the more readily available portion by buckwheat or to the fact that the latter has a greater feeding capacity than clover for the phosphorus of rock phosphate. According to the theory that plants with a high calcium content have a relatively high feeding capacity for phosphorus from rock phosphate, clover and buckwheat should be similar in this respect as both have a high calcium content.

TABLE 9.—*Relation of fineness of rock phosphate to assimilation of phosphorus by buckwheat.*

Additions at rate of 500 lbs. per acre*	Phosphorus in plant %
Grey rock phosphate coarser than 100-mesh	0.267
Grey rock phosphate 100- to 200-mesh	0.281
Grey rock phosphate finer than 200-mesh	0.308
Brown rock phosphate coarser than 100-mesh	0.288
Brown rock phosphate 100- to 200-mesh	0.311
Brown rock phosphate finer than 200-mesh	0.353

*Reaction of soil was pH 4.7.

Further indications regarding influence of fineness on availability of rock phosphate were obtained from plants grown in another series of pot tests with rock phosphate additions at the rate of 500 pounds per acre to soil having a reaction of pH 7. Tennessee rock phosphates from two different sources were compared in this experiment. One was a brown rock phosphate guaranteed by the producer to be 80% finer than 300-mesh; while the other material, designated as grey rock phosphate, was not as finely ground. These phosphates were separated into three degrees of fineness, *viz.*, coarser than 100-mesh, 100- to 200-mesh, and finer than 200-mesh. From the data in Table 9 for

plants grown in this series and represented in Fig. 2 showing the variations in amounts of phosphorus utilized from the different phosphates supplied, it is apparent that phosphorus assimilation increased uniformly with fineness of division. These results indicate that fineness is an important factor affecting availability of rock phosphate.

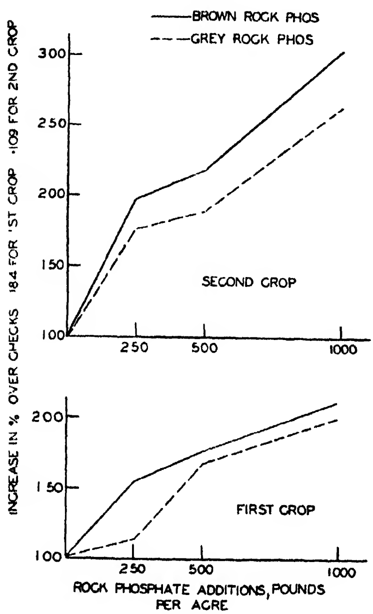

Fig. 3.—Showing phosphorus assimilation from different amounts of grey rock phosphate and more finely ground brown rock phosphate.

EFFECT OF DIFFERENT RATES OF APPLICATION

It was considered that the amounts of phosphates supplied in some of these various tests with plants may have contributed to a luxury consumption of phosphates, thereby obscuring indications regarding availability. Phosphates were therefore applied at different rates to determine to what extent phosphorus assimilation would be influenced by varying amounts of phosphorus at the disposal of plants. Buckwheat assimilated varying amounts of phosphorus from grey rock phosphate and from a more finely divided brown rock phosphate applied at rates of 250, 500, and 1,000 pounds per acre. The fineness of the two phosphates used is stated in Table 8. The percentage of phosphorus in plants of a first and second crop of buckwheat grown in soil with a single addition of the phosphates described is given in Table 10.

Analyses of the plants show an increased phosphorus content with increasing quantities of rock phosphate supplied. It will be noted that more phosphorus was also obtained from the more finely divided, brown rock phosphate. This increase was most pronounced in the first crop with the 250-pound rate of application. Although the phosphorus content was uniformly higher in plants of the first crop, added phosphates produced larger increases over the untreated soil in the phosphorus content of the second crop. These increases from different rates of application are presented graphically in Fig. 3, with the increases based on the check for each crop taken as 100.

TABLE 10.—*Phosphorus assimilated by buckwheat from rock phosphate applied at different rates.*

Phosphate additions, rates per acre	Phosphorus in plants	
	First crop %	Second crop %
None	0.184	0.109
Grey rock phosphate 250 lbs	0.203	0.193
500 lbs	0.304	0.205
1,000 lbs	0.362	0.285
Brown rock phosphate 250 lbs	0.300	0.216
500 lbs	0.319	0.232
1,000 lbs	0.380	0.329
Di-calcium phosphate 500 lbs	0.800	0.401

It is also apparent that less than 500 pounds of rock phosphate did not furnish a large surplus of available phosphorus. From a comparison of the amounts of phosphorus secured by plants from the largest addition of rock phosphate and from di-calcium phosphate, there is evidence that plants had capacity to assimilate more than they could obtain from rock phosphate added at the rate of 1,000 pounds per acre.

SUMMARY

Phosphorus residual from field applications of phosphates was consistently reflected by increased amounts in plants grown in soils from variously treated fertility experiment plats. Although the phosphorus content of plants corresponded closely with the phosphate additions, the indications obtained through the plants were not always in accord with the crop response to soil treatment.

Wheat plants readily assimilated phosphorus from di-calcium and soluble phosphates but had less capacity than buckwheat to utilize phosphorus of rock phosphate.

With limestone and phosphate additions to soil at the same time, phosphorus utilized by plants indicated a decreased availability due to increased basicity. This effect was more pronounced with rock phosphate than superphosphate. Phosphorus assimilation from rock phosphate addition to previously limed field soil was not affected to the same extent as when phosphate and limestone treatments were directly associated. This indicates that remoteness of liming from rock phosphate treatment may have an important bearing on reduction of availability.

Addition of limestone to an acid soil increased assimilation of phosphorus from the natural supply.

An interesting fact shown by the composition of buckwheat grown under different conditions of soil treatment was the large amount of calcium obtained from calcium carbonate with practically no increased assimilation from rock phosphate or di-calcium phosphate, although phosphorus was readily obtained from these sources. Magnesium was also readily secured from magnesium carbonate but not from di-magnesium phosphate.

The phosphorus and calcium relation in plants did not furnish evidence that utilization of calcium and phosphorus from the same source was a factor influencing availability of rock phosphate.

Increased amounts of phosphorus secured by plants from more finely ground rock phosphate indicate that fineness is an important factor affecting availability of this material.

Buckwheat plants had the capacity to assimilate more phosphorus than was obtained from rock phosphate applied at the rate of 1,000 pounds per acre, but less than 500 pounds did not furnish a large surplus of phosphorus available for plants grown in these experiments.

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DIFFERENCES BETWEEN BARNYARD GRASSES AND JAPANESE MILLET[1]

E. N. Bressman and E. S. Fry[2]

The difficulty in distinguishing barnyard grass (*Echinochloa crus-galli* Beauv.), commonly called water grass in the West, from the true Japanese millet (*E. frumentacea* Link), except at the time of maturity of the plants, has led to the substitution of barnyard grass seed for Japanese millet. The names barnyard grass and water grass are used interchangeably in this paper. It is well known that Japanese millet is more productive than the barnyard grasses. Experiences in Oregon in 1928 indicate that care is necessary in obtaining true Japanese millet seed.

Hale[3] states that all of the seed sold to growers in Coos County, Oregon, in 1928, for Japanese millet was not millet but water grass. Yields from this seed were less than half of what was obtained from millet in 1927. Some fields of millet produced as much as 30 tons an acre. He says, "The actual loss in Coos County is hard to estimate as most of the dairymen were depending on the millet for green feed and found themselves without enough green feed to do any good. The biggest damage was done in turning the farmers against the planting of any more Japanese barnyard millet. This crop has just reached the promotion stage in Coos County and it was necessary this year to revert to the demonstration stage again and start things all over."

In response to a request for Japanese millet seed, a California seed house replies in part, "We are enclosing herewith small sample of the type of Japanese millet which is being used in this district. It is known botanically as *Echinochloa crus-galli*. We presume this is the type you wish."

Pine[4] states, "The first millet in Tillamook County, Oregon, was planted in 1925, approximately four acres. In the year 1926 there was a considerable increase in the plantings, and in the year of 1927 it was estimated that 200 acres were seeded to Japanese millet. In the year 1928, there was an increase of approximately 100 acres, making a total of 300 acres. This was the year that barnyard grass was substituted for Japanese millet. The results were so discouraging and so widely distributed over the entire county and regardless of the amount of publicity we used to inform them of this disaster, it

[1]Contributed by the Department of Farm Crops, Oregon Agricultural Experiment Station, Corvallis, Oregon. Published as Technical Paper No. 154 with the approval of the Director. Received for publication July 7, 1931.

[2]Associate Professor and Student, respectively.

[3]Correspondence of July 11, 1929.

[4]Correspondence of July 16, 1929.

is estimated that 25 acres is about all that is planted to Japanese millet this season."

It can readily be seen that this condition required investigation. The writers, therefore, undertook the study reported herein.

REVIEW OF LITERATURE

Engbretson (1)[5] reports that Japanese barnyard millet is the only high-yielding crop that the John Jacob Astor experiment station has tried and found usable during August and September. It is the best late season green feed, taking the place of corn which has not proved suited to most coast conditions of the North Pacific Slope. Another valuable characteristic of the crop is its heavy yield of palatable forage. If the crop is properly planted and conditions are favorable it will give an average yield of 12 to 15 tons an acre. On rich soil with plenty of moisture, a yield of 20 tons an acre is not uncommon. The crop has never been known to lodge, notwithstanding the heavy rains and winds which occur in September.

Kennedy (3) describes three groups of water grasses common in the rice fields of California, as follows: An early form which is short, and matures and drops its seed early, before the rice is headed out; a midsummer form which heads out about the same time as the rice, but drops most of its seed before the rice is harvested; and a late form which is in full seed at the time the rice is harvested.

Four groups of *E. crus-galli* and varieties are described by Jones (2) as present in the rice fields of California. The wide variation among the varieties is shown in his report as follows:

1. The early red varieties which grow from 1½ to 2½ feet high, stool heavily, and have small stems with rather short, compact heads and small seeds. These varieties have purplish green stems, leaves, and heads.

2. The midseason varieties, which grow from 3 to 6 feet high, stool quite heavily, and have rather coarse stems with comparatively long, loose heads and midsized seed. These varieties usually have purplish green stems, leaves, and heads, the purple color being less pronounced than in the early varieties.

3. The late white varieties, which grow from 2 to 5 feet high, stool heavily and have rather coarse stems with comparatively long compact heads. One variety has very large seeds, while another has much smaller seeds. The heads of the late white varieties are yellowish green.

[5]Reference by number is to "Literature Cited," p. 128.

4. Other late varieties, which grow from 2½ to 4 feet tall and stool heavily, have midsized stems with comparatively compact heads and midsized to large seeds. One of these varieties has short, stiff red beards, and another is beardless.

EXPERIMENTAL RESULTS

Samples of true Japanese millet and water grass seed were obtained from various sources and planted in the greenhouse in the spring of 1929. Several selections of the common water grass and "Ankee," a common seed found in rice screenings along with *E. crus-galli*, were planted, but the rate and amount of growth of all selections were so similar that it is not deemed necessary to discuss them in a comparison with Japanese millet. Kennedy (4) states that Ankee is a variety of water grass.

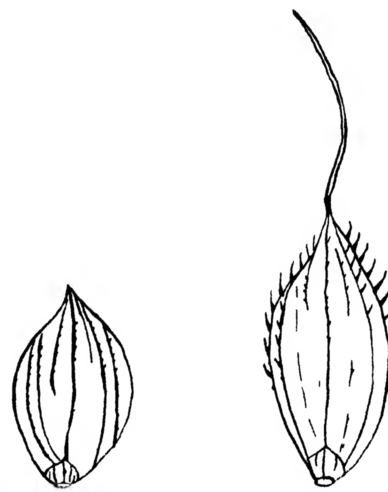

FIG. 1.—Back of seed of *Echinochloa frumentacea* (left) and of *E. crus-galli* (right). This shows extreme differences in the seed of these two species.

The spikelets of the true Japanese millet are usually shorter, broader, and rounder than those of the water grasses and have rather papery glumes which are abruptly pointed only, not awned, and the bristle-like hairs along the nerves are weak and relatively obscure. The kernels are almost round, vitreous, and contain a smaller germ than those of the water grasses. Although the backs of the seeds are fairly round, they have prominently ridged backs as distinguished from the common water grass seeds which are usually less ridged.

In most of the seeds of the common water grass the glumes are bristly with stiff hairs arising from the tubercles along the nerves, the internerves and awns very scabrous. (See Fig. 1.) The widest point on the seed is about one-third from the summit, while in Japanese millet seeds the widest point is half way between the base and tip. This gives a longer appearance to the seeds of the common water grasses as compared to the Japanese millet. The difference is most apparent when viewed from the front or flat side and when the seed retains the glume on this side, which it often does.

No difficulty is encountered in selecting Ankee from the common water grass or from the true Japanese millet. The seeds of Ankee are oval and greenish yellow, and the glumes are finely pubescent with large hairs on the nerves. These seeds are also much larger than those of either the common water grass or the Japanese millet.

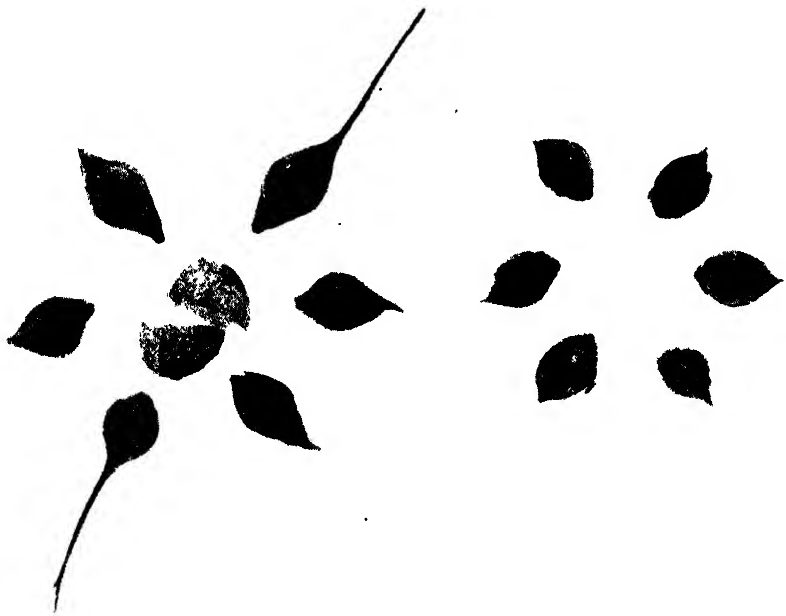

FIG. 2.—*Echinochloa crus-galli* (left) and *E. frumentacea* (right) seed. These seeds are typical of seed lots. The former is from a sample of Japanese millet offered by a seedsman. Note the broken rice kernels in the center.

Samples of seed which were sold as true Japanese millet were planted at the same time and under the same conditions as seed obtained from screenings from a rice mill and with seed known to be true Japanese millet. Fig. 2 shows typical seed of the Japanese millet compared with the water grass. The two distinct types of seed taken from the samples sold as Japanese millet had the same characteristics as those taken from the screenings and produced plants which were identical with those produced from the seeds taken from the screenings.

Most of the glumes had been removed from the backs of the seeds sold as Japanese millet but which proved to be water grasses. A sufficient number of the seeds, however, retain the harsh glumes which have hairs and usually awns, so they can be easily distinguished

from the finer textured Japanese millet seed by any one familiar with these seeds. The presence of broken kernels of rice is an indication

FIG. 3.—From left to right, *Echinochloa frumentacea*, *E. crus-galli*, and Ankee, 70 days after seeding in the greenhouse.

that the seed is water grass rather than Japanese millet. The seeds of the common water grass usually have a lighter brown color than those of the Japanese millet.

The plants of the Japanese millet emerged on the third day, while those of the water grass and Ankee emerged on the fifth day after seeding. The leaves of the Japanese millet were twice as wide as the water grasses at the time of emergence and the same contrast remained throughout the period of growth. The common water grass and the Japanese millet plants had purplish green leaf sheaths at the time of emergence. The common water grasses maintained this characteristic throughout the period of growth, but the Japanese millet plants gradually lost this color as the plants matured. There is a wide variation in the degree of stooling among the strains of water grass. The Japanese millet plants did not stool as readily as the water grass plants. The first half of the growing period showed a large amount of roughening on the edges of the leaves of the Japanese millet, but the water grasses were not entirely free of this characteristic, especially during the latter part of their growing period.

The sheaths of the Ankee plants were green at the time of emergence and remained so. They were rather smooth at first but developed an enormous number of hairs as they matured, becoming velvety by time of maturity. An even greater number of hairs were present at the junction of sheath and blade, making distinct breaks between the rather smooth leaves and the extremely pubescent sheaths. Some of the plants were glabrous.

The heads of the Japanese millet emerged 70 days after date of seeding (Fig. 3). They were compact and of a purplish green color, and since the seeds were awnless, the heads were rather smooth.

A few heads were out 80 days after seeding on the strain of common water grass which stooled to the greatest extent. They were light green, rather compact, and the seeds were awned. The other strains of water grass and Ankee required more than 90 days to head.

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THE EFFECTS OF FERTILIZATION ON THE CHEMICAL COMPOSITION OF VEGETATION IN PASTURES[1]

B. A. Brown[2]

The chemical composition of pasture herbage may be influenced by several factors. Existing data indicate that the most important causes of such differences are: Age of plants; species present; fertility of soil or fertilization; climatic conditions; date of sampling; rate of grazing; and competition from weeds, bushes, and trees. The rather extensive mass of literature on which the above statements are based will not be reviewed here. Those who may desire to study the involved relationships further are referred to the June, 1929, number of this Journal, in which are published the papers, including rather complete bibliographies, presented at the pasture management symposium held in New York City in December, 1928.

This paper will be confined to a presentation and a discussion of the results obtained from analyzing samples of the vegetation growing in 1929 and 1930 in the experimental pastures at the Storrs (Conn.) Agricultural Experiment Station. These experimental pastures are located on rough, untillable land and therefore may be classified as "permanent;" at least they have not been tilled, fertilized, or seeded for 40 or more years, except the topdressed fertilizers applied during the course of the experimental work now in progress. Since 1921, the nine 4-acre pasture plots have been grazed with yearling steers for the purpose of measuring the production of feed under actual pasture conditions. In 1924, after 3 years of preliminary grazing with no treatment, each pasture was fertilized. The treatments varied on each plot and included separate and combined applications of limestone, superphosphate, muriate of potash, and nitrogen as urea, sulfate of ammonia, or nitrate of soda. Mineral fertilizers have been applied in 1924 and 1929 only, while nitrogenous materials have been added annually since 1927. All fertilizers have been topdressed in the early spring months.

METHODS OF SAMPLING

Samples of the short vegetation growing in the variously fertilized pastures were taken on two dates, in 1929, *viz.*, May 18 and June 27, and on five dates in 1930, *viz.*, April 29, May 14, June 10, June 25, and August 5. With the exception of June 27, 1929, when a lawnmower

[1]Contribution from Department of Agronomy, Storrs (Conn.) Agricultural Experiment Station. Received for publication July 11, 1931.

[2]Associate Agronomist.

was used, all samples were cut with grass shears. Small amounts of the green herbage less than 4 inches high were collected from numerour spots distributed over the entire area in each pasture. Although the sampling was more or less at random, care was taken to avoid obviously unrepresentative areas, such as around trees, water troughs, bush patches, dunghills, etc. In addition to the short (less than 4 inches) pasturage, samples of four species in the early bloom stage were collected separately from ungrazed patches in June, 1929.

In all cases, the samples were weighed within a short time after cutting and spread in paper-lined trays in an unheated room until air-dry. Then they were placed in paper bags and stored until early winter, when they were ground and analyzed.[3]

WEATHER CONDITIONS

Because of extremely dry weather, neither 1929 nor 1930 were ideal seasons for a study of this kind. In 1929, June and especially July had very small amounts of precipitation and little growth occurred during the latter month. Although a few heavy showers fell early in August, they did not continue in sufficient amounts to stimulate much activity in the pasture vegetation, which in most seasons is normally low at this period

In 1930, a dry period, severe enough to necessitate the removal of most of the cattle from the experimental pastures, occurred in the latter part of April and the first half of May. The precipitation in June and July, although below the averages for those months, was sufficient to permit of some growth until a very hot, dry period in early August stopped production. As August and September were extremely dry months, scarcely any more pasturage was obtained in 1930.

BOTANICAL DIFFERENCES

In studying the analyses of the short vegetation, it should be borne in mind that the values given are analyses of representative samples of pasturage, the *botanical* composition of which varied greatly. Thus, a considerable part of the chemical variations noted are *directly* due to differences in the proportions of the several species, and their prevalence was greatly influenced by the kind of fertilizers applied. It should also be remembered that the samples were from pastures which have received the same general fertilizer treatments for several years previous to those in question and therefore the character of the

[3]Analyses were made in the Department of Analytical Chemistry of the Connecticut Agricultural Experiment Station and methods of the Association of Agricultural Chemists were employed.

vegetation reflects the long-time effects of the various types of fertilization. As any appreciable amount of white clover (*Trifolium repens* L.) in the herbage has marked effects on the analyses, the estimated percentages of the pasturage furnished by this plant are given in Table 1.

TABLE 1.—*Proportions of white clover in vegetation of variously fertilized pastures (estimated percentages).*

Fertilizer treatment*	June, 1929	June, 1930
None	1	0.5
LK	2	1.0
P	14	2.5
PK	25	6.0
PKN	18	2.0
PL	41	15.0
PLK	55	18.0
PLKNN[1]	18	1.5
PLKNN	30	1.0

*P = Superphosphate (16%) at 500 pounds per acre in 1924 and 1929.
L = Ground limestone at 2,000 pounds per acre in 1924 and 1929.
K = Muriate of potash at 100 pounds per acre in 1924 and 1929.
N = Nitrogen at 28 pounds per acre annually in April.
NN = Nitrogen at 56 pounds per acre annually in April.
NN[1] = Nitrogen at 56 pounds per acre annually, but one-half in July.

The data in Table 1 show strikingly the effects of fertilization on the prevalence of white clover. Scarcely any was found where no phosphorus was applied and the most where the treatments were superphosphate and limestone or superphosphate, limestone, and potash. The use of nitrogen carriers has reduced markedly the proportion of clover, particularly in 1930.

In regard to grasses, four species contribute the bulk of the pasturage from Gramineae. The amount of any one of these species varies with the fertilizer treatments. However, Rhode Island bent grass (*Agrostis capillaris* L.) occupies a large share of the turf in these pastures and sweet vernal (*Anthoxanthum odoratum* L.) is also very much in evidence on all plots. Kentucky bluegrass (*Poa pratensis* L.) fluctuates markedly, being present in large amounts where lime and phosphorus or nitrogen and phosphorus carriers have been used and almost absent on the unfertilized pasture. On the other hand, wild oat or "poverty" grass (*Danthonia spicata* (L.) Beauv.) is most abundant where Kentucky bluegrass is least prevalent and is not much in evidence under any treatments which include phosphorus. Thus, in the unfertilized pasture, Rhode Island bent, sweet vernal, and particularly wild oat grass are prominent and provide most of the grazing, while on the pastures receiving mineral fertilization, wild

oat grass is practically absent, Rhode Island bent and sweet vernal greatly reduced, but white clover and Kentucky bluegrass are present in large amounts. In between these extremes fall the other variously fertilized pastures under consideration.

DISCUSSION OF RESULTS

For the sake of brevity, the fertilizer symbols, explained in Table 1, will be used in discussing the results. The various constituents will be taken up in the order in which they appear in Tables 2 and 3, where the analyses of the short vegetation in 1929 and 1930 are shown. Table 4 gives the analyses of four species sampled separately from ungrazed patches in the various pastures in June, 1929. The results of both years will be considered together.

TABLE 2.—*Effect of fertilizers on the chemical composition of the vegetation in grazed, permanent pastures in 1929.*

Fertilizer treatment*	Percentage composition of dry matter								Ca:P ratio
	Total ash	N	Fiber	N-free extract	Fat	K	P	Ca	
				Samples Taken May 18, 1929					
PK	9.78	3.16	21.57	45.19	3.70	2.43	0.38	0.78	2.0
PKN	8.90	4.02	21.09	40.73	4.14	3.00	0.43	0.64	1.5
PLK	9.33	3.64	20.72	43.50	3.74	2.31	0.39	0.99	2.4
PLKNN[1]	9.67	3.45	21.16	43.78	3.86	2.53	0.35	0.83	2.4
PLKNN	10.81	4.04	21.13	38.83	4.00	2.81	0.39	0.74	1.9
				Samples Taken June 27, 1929					
None	15.96	1.87	24.35	45.22	2.81	1.30	0.22	0.79	3.6
P	12.50	2.32	25.22	44.73	2.95	1.57	0.32	0.72	2.3
PL	11.33	3.38	22.27	42.25	3.02	1.68	0.38	1.09	2.9
PLK	12.95	3.26	21.68	42.22	2.75	1.87	0.39	1.20	3.1
PLKNN[1]	12.10	2.67	23.02	45.35	2.84	1.59	0.32	0.97	3.0
PLKNN	12.37	2.84	22.64	44.58	2.69	1.57	0.31	0.85	2.7
PK	11.78	2.81	24.50	43.30	2.89	1.89	0.37	0.91	2.5
LK	12.94	2.09	24.27	46.56	3.19	1.67	0.20	0.87	4.4
PKN	13.60	2.70	23.49	43.09	2.98	1.74	0.34	0.75	2.1

*See Table 1 for explanation of symbols.

TOTAL ASH

The influence of fertilizers on the total ash content of the dry matter is not very much in evidence. There is a marked tendency for the ash content to increase with the advance of the season and this is particularly true of the results in 1929. In that year, vegetation from the five pastures sampled on two dates analyzed 9.70% ash on May 18 and 12.56% on June 27, or an increase of 29% between those dates. Similar increases may be noted in the results for 1930, being especially large between June 25 and August 5 for all pastures excepting the one

receiving part of its nitrogenous fertilizer in July. Probably a considerable share of the increases noted as the season advances is due to adhering dust and sand particles, for the analyses for P, K, and Ca do not show corresponding increases.

TABLE 3.—*Effect of fertilizers on the chemical composition of the vegetation in grazed, permanent pastures in 1930.*

Fertilizer treatment*	Analyses as percentages of dry matter					
	April 29	May 14	June 10	June 25	August 5	Average
			Total Ash			
None	—	6.70	6.37	8.39	—	7.15
LK	—	6.93	7.59	8.45	—	7.66
P	6.83	6.62	7.60	8.97	—	7.51
PK	7.18	6.87	8.48	9.19	—	7.93
PKN	7.40	8.35	8.97	9.10	11.13	8.99
PL	6.68	7.45	8.64	8.61	12.96	8.87
PLK	7.49	8.30	8.98	9.30	14.11	9.64
PLKNN[1]	6.97	7.37	8.14	8.06	8.46	7.80
PLKNN	6.96	6.98	7.76	8.24	9.51	7.89
			Nitrogen			
None	—	3.51	2.23	2.34	—	2.69
LK	—	3.08	2.50	2.72	—	2.77
P	4.30	3.26	3.24	2.83	—	3.41
PK	3.36	4.44	3.20	3.20	—	3.55
PKN	5.22	4.17	4.25	3.64	3.06	4.07
PL	4.29	3.74	3.76	3.48	3.37	3.73
PLK	4.26	3.93	4.13	3.43	3.29	3.81
PLKNN[1]	4.61	3.71	4.29	3.45	3.86	3.98
PLKNN	5.28	4.23	4.65	3.61	2.48	4.05
			Fiber			
None	—	20.22	26.71	26.11	—	24.35
LK	—	21.81	25.65	25.61	—	24.36
P	16.95	22.55	24.57	25.40	—	22.37
PK	22.41	16.99	26.06	23.70	—	22.29
PKN	17.18	19.92	22.92	24.19	21.69	21.43
PL	16.64	20.04	21.74	23.17	19.45	20.21
PLK	16.96	19.84	22.21	23.42	19.51	20.39
PLKNN[1]	17.96	21.67	23.12	24.81	23.04	22.12
PLKNN	17.13	19.82	22.91	25.61	24.50	21.99
			Nitrogen-free Extract			
None	—	47.48	50.35	48.12	—	48.65
LK	—	48.40	48.01	46.37	—	47.59
P	45.61	47.54	44.46	44.80	—	45.60
PK	46.07	44.29	42.46	44.10	—	44.23
PKN	38.63	41.78	38.13	40.84	44.30	40.74
PL	45.66	45.39	42.97	43.04	42.91	43.99
PLK	44.78	43.52	39.99	42.38	42.29	42.59
PLKNN[1]	42.34	44.24	38.61	42.36	40.24	41.56
PLKNN	38.80	43.02	36.98	40.46	46.83	41.22

*See Table 1 for explanation of symbols.

TABLE 3.—*Continued.*

Fertilizer treatment*	Analyses as percentages of dry matter					
	April 29	May 14	June 10	June 25	August 5	Average
			Fat			
None	——	3.66	2.65	2.78	——	3.03
LK	——	3.63	3.10	2.60	——	3.11
P	3.75	2.92	3.09	3.14	——	3.23
PK	3.31	4.09	3.02	3.02	——	3.36
PKN	4.19	3.91	3.45	3.09	3.78	3.68
PL	4.23	3.75	3.13	3.42	3.59	3.62
PLK	4.16	3.75	2.99	3.45	3.50	3.57
PLKNN[1]	3.90	3.56	3.34	3.22	4.14	3.63
PLKNN	4.10	3.74	3.31	3.11	3.65	3.58
			Phosphorus			
None	——	0.20	0.17	0.21	——	0.19
LK	——	0.21	0.20	0.21	——	0.21
P	0.29	0.30	0.28	0.31	——	0.30
PK	0.29	0.32	0.32	0.34	——	0.32
PKN	0.36	0.32	0.35	0.34	0.32	0.34
PL	0.28	0.31	0.33	0.33	0.30	0.31
PLK	0.31	0.33	0.35	0.35	0.34	0.34
PLKNN[1]	0.31	0.32	0.35	0.31	0.27	0.31
PLKNN	0.35	0.32	0.32	0.31	0.27	0.31
			Potassium			
None	——	2.17	1.59	1.78	——	1.85
LK	——	2.01	1.84	2.08	——	1.98
P	2.38	2.03	2.11	2.15	——	2.17
PK	2.23	2.47	2.27	2.41	——	2.35
PKN	2.53	2.29	2.55	2.69	1.88	2.39
PL	2.23	1.96	2.14	2.27	1.70	2.06
PLK	2.29	2.14	2.37	2.39	1.96	2.23
PLKNN[1]	2.39	2.17	2.28	2.42	2.17	2.29
PLKNN	2.51	2.22	2.64	2.51	1.72	2.32
			Calcium			
None	——	0.59	0.52	0.58	——	0.56
LK	——	0.63	0.68	0.67	——	0.66
P	0.58	0.59	0.62	0.68	——	0.62
PK	0.66	0.55	0.70	0.70	——	0.65
PKN	0.55	0.74	0.60	0.59	0.68	0.63
PL	0.58	0.97	0.98	0.93	1.00	0.89
PLK	0.67	1.05	0.93	0.85	0.90	0.88
PLKNN[1]	0.58	0.74	0.72	0.61	0.65	0.66
PLKNN	0.53	0.68	0.59	0.60	0.69	0.62
			Ca:P Ratios			
None	——	3.0	3.1	2.8	——	3.0
LK	——	3.0	3.4	3.2	——	3.2
P	2.0	2.0	2.2	2.2	——	2.1
PK	2.3	1.7	2.2	2.1	——	2.1
PKN	1.5	2.3	1.8	1.7	2.2	1.9
PL	2.1	3.1	3.0	2.8	3.3	2.9
PLK	2.2	3.2	2.7	2.4	2.6	2.6
PLKNN[1]	1.9	2.3	2.1	2.0	2.4	2.1
PLKNN	1.5	2.1	1.8	1.9	2.6	2.0

*See Table 1 for explanation of symbols.

TABLE 4.—*Effect of fertilizers on the chemical composition of pasture species in early bloom stage in 1929.*

Fertilizer treatment*	Percentage composition of dry matter								Ca :P ratio
	Total ash	N	Fiber	N-free extract	Fat	K	P	Ca	
	Sweet Vernal (*Anthoxanthum odoratum*, L.)								
None	5.94	1.58	33.04	49.00	2.15	1.54	0.17	0.37	2.2
P	5.87	1.68	32.25	49.11	2.26	1.71	0.28	0.43	1.5
PL	6.56	1.85	31.77	47.37	2.74	1.83	0.28	0.49	1.8
PLK	6.46	1.60	30.34	50.68	2.53	1.74	0.29	0.45	1.6
PLKNN	6.24	1.88	31.09	48.13	2.78	1.78	0.25	0.44	1.8
LK	5.98	1.41	33.79	49.19	2.20	1.86	0.13	0.35	2.7
PKN	5.45	1.63	30.70	51.50	2.15	1.55	0.29	0.37	1.3
Average of 5 "P" plots	6.12	1.73	31.23	49.36	2.49	1.72	0.28	0.44	1.6
	Kentucky Bluegrass (*Poa pratensis* L.)								
None†	7.23	2.38	29.44	45.53	2.92	2.31	0.25	0.46	1.8
P	6.26	2.10	29.08	48.52	2.99	2.10	0.31	0.55	1.8
PL	6.56	1.95	31.13	47.36	2.76	1.82	0.31	0.41	1.3
PLK	6.61	2.01	31.10	47.05	2.70	2.03	0.30	0.42	1.4
PLKNN	7.50	2.70	29.40	43.12	3.11	2.66	0.31	0.54	1.7
LK	6.43	1.66	32.27	48.29	2.64	1.85	0.18	0.34	1.9
PKN	6.64	2.59	31.20	43.08	2.90	2.08	0.30	0.36	1.2
Average of 5 "P" plots	6.71	2.27	30.38	45.83	2.89	2.14	0.31	0.46	1.5
	White Clover (*Trifolium repens* L.)								
P	9.23	3.40	19.77	46.86	2.90	1.92	0.34	1.44	4.2
PL	10.11	3.62	19.90	44.03	3.34	2.07	0.39	1.57	4.0
PLK	9.32	3.69	19.68	45.18	2.79	2.27	0.36	1.26	3.5
PLKNN	10.06	3.54	21.67	42.86	3.31	2.36	0.33	1.31	3.5
PKN	10.46	4.47	18.12	40.36	3.14	2.88	0.41	1.15	2.8
Average	9.84	3.74	19.83	43.86	3.10	2.30	0.37	1.35	3.6
	Rhode Island Bent (*Agrostis capillaris* L.)								
PK	6.87	1.57	32.66	48.31	2.34	1.91	0.27	0.35	1.3
PKN	6.75	1.78	31.42	48.32	2.39	1.99	0.28	0.45	1.6

*See Table 1 for explanation of symbols.
†Bluegrass only found around dung-hills and decaying stumps on untreated plot.

The possible effect of rains previous to sampling on the ash in or on pasture vegetation is of interest. Very large amounts of ash were found in the samples of June 27, 1929. Two days previous to that date nearly an inch of precipitation had fallen. Scarcely any rain had fallen for several days before the April 29 and May 14, 1930, samples were taken, yet the ash contents are uniformly lower than in the June 10 and 25 cuttings, which were immediately preceded by quite heavy showers. The still higher ash contents of the vegetation on August 5 were found in samples taken after a week of dry, hot weather. Thus, one cannot decide from this conflicting evidence if rains increased or decreased the amounts of soil adhering to the herbage.

NITROGEN

Nitrogen is reported as the percentage of the element rather than as protein (percentage of nitrogen x 6.25), because it is very doubtful if all of the nitrogen in young, rapidly growing herbage is in protein, or even organic, form. Moreover, the distribution of forms of nitrogen as determined on the air-dry material does not serve as an adequate basis for judgment as to the kind and amount of nitrogenous substances in the green forage as it is consumed because of enzymic or other transformations which occur during the interval of drying. This is well illustrated by the work of Vickery, *et al.*[4], upon tobacco. However, in a few instances, the distribution of several forms of nitrogen in the air-dry material was determined by conventional methods and this is not without value provided the reservation just noted is kept in mind. Our results, given below, were obtained by analyzing the air-dry samples of May 18, 1929. The fertilizers had been applied nearly a month previous to that date. The results were as follows:

	Percentage in dry matter	
Form of N	Minerals only	Minerals plus N
Nitrate	0.00	0.00
Ammoniacal	0.16	0.08
Water-soluble organic	1.18	1.50
Water-insoluble organic	2.40	2.62
Total	3.74	4.20

These data show there were practically no differences in the proportions of the total nitrogen in the various forms determined in the air-dried samples from the two plots in question. The data also show that *all* treatments which included P were effective in increasing the nitrogen content of the pasturage. However, regardless of the addition of other plant nutrients, the greatest amounts of nitrogen were found in the herbage from pastures receiving either PL or PN fertilization. Thus, in 1929, the samples of May 18 analyzed PLK, 3.64% N; and PLKNN, 4.04% N. On June 27, by which date clover was more in evidence on the PL plots and the grass was making a less rapid growth in the PN pastures, the following results obtained: PLK, 3.26% N; and PLKNN, 2.89% N.

The analyses of the 1930 samples show that even the relatively poor quality vegetation on the unfertilized pasture had 3.5% N on May 14 when it was in an immature stage. On April 29, by far the largest amounts of nitrogen were found in the grass from the pastures

[4]Unpublished data obtained at the Connecticut Agricultural Experiment Station.

receiving fertilizer N, exceeding 5% in two samples, or about 1% more than in the PL plots. However, by May 14, the nitrogen content of the pasturage from all plots had decreased, that from the N pastures showing the greatest decline, although still somewhat above the vegetation with PL treatments. These differences were maintained in the June 10 samples, but on June 25 practically all samples from the PL or PN pastures contained dry matter with the same—about 3.5%—amount of nitrogen. On August 5, the vegetation from the PL plots exceeded the PN herbage in nitrogen content except where additional nitrogenous fertilizer had been applied in July.

In general, the data show that an exceedingly high nitrogen content of pasture vegetation may be obtained by applying soluble nitrogenous fertilizers, but that these high levels are not maintained unless additional nitrogen is added frequently. The nitrogen content of the herbage from the PL or PLK pastures was much more uniform throughout the season and averaged more in 1929 and almost as much in 1930 as where nitrogenous fertilizers were applied. The high nitrogen content of the PL pasturage on the later dates of sampling is undoubtedly due to the relatively large proportions of white clover, the dry matter of which, as is shown in Table 4, contains, even in the blooming stage, over 20% crude protein.

Yearling steers were grazed on these pastures, beginning April 29, 1930, when the herbage on the PN plots contained over 5% nitrogen, or over 30% protein if calculated in the usual way, and as far as could be observed, suffered no ill effects from a ration considered too narrow (less than 1:2) for practically any herbivorous animal. Based on the number of steers maintained and their gains in weight, the production of feed on three of the experimental pastures was as follows:

Fertilizer	1929	1930
None	100	100
PL	311	283
PLKNN	342	282

FIBER

The fiber in the dry matter seldom was below 20% except in the very young herbage sampled April 29, 1930. On the other hand, rarely was it above 25%. The data indicate a tendency for the fiber to increase as the season progresses and this is particularly true where essential fertilizer elements had not been used. On most dates of sampling, the lowest amounts of fiber were found in the samples from the PL plots. However, the differences between the PL and PN plots are small and probably of little practical importance where reasonably

close grazing is practiced. Otherwise, a distinct advantage would be held by the pastures treated only with minerals, due to the much greater prevalence of white clover which does not lose its succulence with increasing age nearly as rapidly as the grasses.

NITROGEN-FREE EXTRACT

In general, the nitrogen-free extract content of the dry matter varies inversely with the nitrogen. It constituted slightly over 40% of the dry matter in the vegetation from the better pastures, but on one occasion reached 50% in the unfertilized plot. The averages in 1930, when from three to five samples per pasture were analyzed, were as follows:

Fertilizer treatment	N-free extract %
LK and unfertilized	48.12
P and PK	44.92
PL and PLK	43.29
PKN and PLKNN	41.17

FAT OR ETHER EXTRACT

The fat content of the pasture herbage seems to vary conversely with the nitrogen and inversely with the nitrogen-free extract and fiber, although there are a few exceptions to this general conclusion. The high fat content where the nitrogen was also high offsets some of the narrowing effect on the nutritive ratio due to decreasing nitrogen-free extract in those cases.

In general, the effects of fertilization on the fat content are not as striking as in the case of nitrogen. Nevertheless, the treatments containing PL or PN increased the proportion of fat in most cases, particularly on the later dates of sampling. In this respect, there seem to be no consistent differences between the PL and PN pastures.

PHOSPHORUS

With calcium, the phosphorus content of animal feeds has been studied extensively in recent years. In the case of pastures, it has been amply demonstrated that the extremely low amounts of phosphorus frequently found in the vegetation growing on deficient soils in several parts of the world are the causes of many troubles in the breeding and growing of animals. Therefore, the effects of fertilization on the content of this mineral in the pasturage is particularly interesting.

The data in Tables 1 and 2 show clearly that in all cases the application of superphosphate, regardless of other fertilization, increased markedly the P content of the vegetation. On some dates of sampling

these increases are about 100%. The average percentages, dry matter basis, are as follows:

Fertilizer	Pastures averaged	1929 %	1930 %
No phosphorus	2	0.21	0.20
Phosphorus	7	0.35	0.32

As might be expected, none of the other fertilizers affected the phosphorus content of the herbage nearly as much as did superphosphate. In fact, the data do not warrant the conclusion that the other fertilizers were at all effective. Yet in 10 of the 11 possible comparisons the phosphorus content is higher where potash was added to the P or PL treatments. The same is also true in 10 of 11 cases where lime was included with the P or PK fertilizers. In only 4 of 13 instances where nitrogenous fertilizers were applied was the phosphorus in the herbage increased. The averages are given below:

Fertilizer	Phosphorus in dry matter %
P and PK	0.32
PL and PLK	0.34
P and PL	0.31
PK and PLK	0.34
PK and PLK	0.345
PKN and PLKN	0.338

Two explanations are suggested for the increased phosphorus content noted in practically all instances where lime or potash were applied. First, that they kept the phosphorus added in the superphosphate in a more available condition for plants. Laboratory tests for available phosphorus in the soil from these pastures have actually given higher readings where *lime* was applied with *superphosphate*, but such differences could not be distinguished in the case of potash. Second, that the lime or potash has affected the botanical composition. Reference to Table 1 will show that there was a greater proportion of clover on pastures receiving lime or potash. In 1929 and 1930, the limed pastures had over three times as much and the potash plots about one-third more clover. Analyses of separate species (Table 4) showed that clover contained more phosphorus than the grasses and therefore it seems logical to assign to the increase in clover at least some of the increased phosphorus content of representative samples of the vegetation. Moreover, an increase in bluegrass has usually accompanied the spread of clover in these pastures

and bluegrass was found to be somewhat richer in phosphorus than sweet vernal or Rhode Island bent.

A third theory to explain the larger phosphorus content of vegetation where lime or potash had been added is that those materials were instrumental in making available some of the soil's supply of phosphorus. Inasmuch as the samples from the pasture receiving lime and potash only contained no more phosphorus than those from the untreated land, this theory is scarcely tenable in this instance.

POTASSIUM

Although no significant increases in the production as measured by grazing have been obtained from applying potash, in 11 of 12 direct comparisons the potassium content of the pasturage is larger when the P or PL treatments were augmented by muriate of potash. The average differences are about the same on limed and unlimed plots, indicating that the greater amounts of clover on the limed land were not responsible for the gain in potassium. As this soil seems to furnish enough potash for the maximum production of the pastures treated with minerals, it is probable that the additional potassium found in the herbage of the K plots represents "luxury consumption." This idea is supported by the fact that each of three species, analyzed separately, contained more potassium when grown on the PLK than on the PL pastures.

From the 1929 data, it is evident that the more rapidly growing grass of May 18 was much richer in potassium than that sampled June 27, when, due to dry weather and advance in season, the rate of production was considerably reduced. During the same period in 1930, with much more favorable weather in June, no consistent decreases in potassium occurred. However, the samples taken August 5, during a dry period, show a marked reduction.

CALCIUM

Clover normally contains so much more lime than the grasses that one might expect a positive correlation between the calcium content of the vegetation and its proportion of clover, provided, of course, the estimations of clover stands and the sampling are reasonably accurate. A study of the data shows that in most instances the percentage of calcium varies with the amount of clover, being very noticeable where the proportions of clover were large, particularly under the PL or PLK treatments. Thus, in 1929, the two pastures so fertilized, produced forage with 20% more calcium in the dry matter than any other pasture and nearly 50% more than the untreated, P,

or NPK plots. In 1930, although the April 29 samples from the PL and PLK pastures did not contain more Ca than the others, due to the late starting habit of clover, their average Ca content for the season is 30% above that of any other pasture. The untreated pasture again produced forage with a low Ca content, but no significant differences seem to exist among the others.

The results of investigations at other experiment stations have indicated an upward trend in the Ca content of pasturage as the season advances, reaching a peak in mid-summer and then gradually declining. In our work, all of the five pastures sampled on May 18 and June 27, 1929, had higher percentages of Ca on the latter date. In 1930, all but one of the seven May 14 samples were above those of April 29 in Ca content. However, no consistent trends are indicated by the other 1930 analyses and it seems quite probable that the increases noted in the early parts of both years are largely due to the more rapid growth of white clover as the seasons advanced.

However, all of the differences noted in Ca content should not be ascribed to the varying amounts of clover. The analyses of separate species in the early bloom stage, given in Table 4, show strong indications of the effects of different fertilizers on the lime they contain. For example, sweet vernal and Kentucky bluegrass and also white clover from the NPK pasture have low percentages of Ca. The omission of superphosphate from the fertilizer (LK plot) resulted in very low Ca contents for both of the grasses mentioned. The last observation and the fact that the application of superphosphate alone produced grasses and clover with rather high amounts of Ca would lead one to think these plants obtained at least some of their Ca requirements from either the calcium phosphate or calcium sulfate carried by that fertilizer.

CALCIUM-PHOSPHORUS RATIOS

The fertilizer treatments have affected appreciably the relative amounts of calcium and phosphorus in the pasturage. In this respect, the variations between the different pastures are much smaller for the May 18 cutting of 1929 and the April 29 cutting of 1930 than for the subsequent dates of sampling. As the value of this ratio depends on both the Ca and P contents, it is obvious that similar values may be the result of entirely different causes. Thus, there are two groups of fertilizer treatments which have produced vegetation with distinctly higher Ca:P ratios. One group includes those treatments from which P is omitted, namely, the unfertilized and the LK pastures, and the large values of the ratios are due primarily to very low phosphorus

contents of the grasses growing on this P-deficient soil. The percentages of Ca for both pastures are near the average. Of the two, the LK pasturage has somewhat larger Ca:P ratios.

The other high ratio group also consists of two treatments, namely, PL and PLK. In this group, the high values are due to the large amounts of Ca in the herbage, for the P content is also high. As discussed under "calcium", the high percentages of Ca in the PL and PLK pasturage are largely due to a radical change in the botanical composition of the flora, chiefly to the prevalence of white clover, which in the early bloom stage in 1929 on five differently treated pastures had an average Ca:P ratio of 3.7:1. Thus, whereas in the first group, the high values were due to low P contents of "original" species, in the second group, they are due to the high Ca content of a "brought in" species.

The vegetation from all of the other pastures contained Ca and P in approximately the theoretically ideal ratio of 2:1. Where both lime and "complete" fertilizer were applied, the ratios tend to be higher than where lime was omitted. This result seems to be due to a higher Ca content in the grasses on the limed plots and not to a greater prevalence of clover. (See Table 4.)

To avoid large errors resulting from "individuality" in small groups, the steers used to graze the pastures in this experiment have been moved to a different pasture at about 2-week intervals. This practice has made it impossible to determine what would have been the effects of continuous grazing on vegetation of such widely varying botanical and chemical composition. However, in recent years, the rotation of the animals has been, in so far as possible, within groups of pastures with vegetation of similar botanical and chemical characteristics. The data obtained in this manner strongly suggest that all of the pastures have provided a satisfactory ration for the growth of the young cattle in question and that "quantity" of feed has been more important than "quality". Nevertheless, it has been observed that steers which have been grazing on the highest producing plots (PL and PN) will eat bushes and weeds with apparent relish when opportunity for doing so is afforded. The cause or causes for this habit have not been determined. The common outstanding chemical difference between the vegetation in the PL or PN and other plots is in the content of nitrogen.

OTHER ELEMENTS

In both years, the amounts of Si, Fe, Al, Ca, Mg, Mn, Cl, and S in the composited samples from several pastures were determined. In

1929, the samples were all collected on June 27 and composited into three groups according to fertilizer treatments as follows: (1) None; (2) PL and PLK; and (3) PKN and PLKN. In 1930, all of the samples from each of six pastures were composited. Thus, the number of individuals mixed together depended on the times the vegetation was sampled and varied from three to five that season. The results are tabulated in Table 5.

TABLE 5.—*Si, Fe, Al, Ca, Mg, Mn, Cl, and S in composited samples of vegetation in variously fertilized pastures.*

Fertilizer treatment*	No. samples composited	Percentage in dry matter of							
		Si	Fe	Al	Ca	Mg	Mn	Cl	S
Samples Collected June 27, 1929									
None . . .	1	5.03	0.77	0.04	0.79	0.35	0.05	0.50	0.36
PL and PLK .	6	2.20	0.34	0.00	1.02	0.34	0.02	0.76	0 40
PKN & PLKNN	4	3.17	0.43	0.05	0.79	0.30	0.03	0.92	0.40
Samples of All Dates Collected in 1930									
None . . .	3	1.19	0.07		0.51	0.16	0.030	0.55	0.23
P. . .	4	0.93	0.08		0.53	0.18	0.032	0.64	0.28
PK .	4	0.98	0.11		0.59	0.19	0.032	0.72	0.29
PL. . .	5	1.23	0.17		0.77	0.25	0.015	0.65	0.28
PLK	5	1.48	0.30		0.77	0.26	0.019	0.74	0.31
PLKNN . . .	5	0.85	0.15		0.51	0.21	0.014	0.65	0.36

*See Table 1 for explanation of symbols.

It may be noted that in practically all instances, the values are smaller for the vegetation sampled in 1930. These differences are especially marked in the case of Si, Fe, and Al. The reasons for these wide variations between the two seasons are not known, but as the three elements varying the most (Si, Fe, and Al) comprise about 80% of all constituents of the soil in these pastures, it is quite probable that the vegetation collected June 27, 1929, carried a considerable amount of soil. If this supposition is true, it seems evident that the heavy rainfall—about 1 inch—of June 25 soiled rather than cleansed the grass.

In view of what has just been said, it may seem idle to discuss the data further. However, in some cases, consistent trends are evident. For example, the Ca content was markedly higher in the samples from the PL or PLK pastures. In 1930, but not in 1929, the amounts of Mg varied with Ca in five of the six cases. The amounts of Mn, an element rendered more insoluble and therefore less available by liming, are consistenly about 100% greater in the vegetation from the unlimed pastures.

In both years, the unfertilized pasture produced herbage with the lowest percentages of Cl, a result in general agreement with those of

Godden, who found positive correlations between the amounts of K, P, Ca, and Cl in the "eaten" grass of the several Scotch Highland pastures[5], but contrary to his data obtained on "Moorland" pasture where *all* fertilizers *depressed* the amounts of Cl in the vegetation.[6]

The total S content of the pasturage was higher on all fertilized plots, especially on the PLKNN pasture in 1930. As S is a component of protein, when an increase or decrease in one of these materials occurs, a similar change may be expected in the other. In 1929, one-half of the S was in the ash. The distribution was not determined in 1930

SUMMARY

The chemical analyses of the herbage collected from several variously fertilized, permanent pasture plots in the grazing experiment at the Storrs (Conn.) Experiment Station are reported.

In 1929, the short (less than 4 inches) vegetation was sampled on May 18 and June 27 and four species in the early bloom stage were collected separately during June. In 1930, the sampling dates for most pastures were April 29, May 14, June 10, June 25, and August 5. The samples, except those of June 27, 1929, when a lawnmower was used, were cut with grass shears and all were air-dried without artificial heat. The analyses were made in the Department of Analytical Chemistry of the Connecticut Agricultural Experiment Station and the methods of the Association of Agricultural Chemists were employed.

The influence of fertilizers on the *total ash* content is not very evident. There is a marked tendency for the amount of ash to increase with the advance of the season. The results are thought to have been influenced by adhering soil.

All fertilizers increased the nitrogen content of the pasturage. Early in the season, greater amounts of nitrogen were found where nitrogenous fertilizers were applied, but the averages for each year were about the same for the PL and PN treatments. In general, white clover influenced the nitrogen content of representative samples of herbage as much as fertilizer nitrogen.

No nitrate and little ammoniacal nitrogen were found in the air-dry samples of May 18, 1929, one month after fertilization. In this respect, no differences were noted between the PLK and PLKNN fertilizers. However, analyses of air-dry materials are doubtful

[5]GODDEN, WILLIAM. Report on the chemical analyses of samples of pasture from various areas in the British Isles. Jour. Agr. Sci., 16: 78–88. 1926.

[6]——————. Report of the effect of fertilizers on the mineral content of pastures. Jour. Agr. Sci., 16: 98–104. 1926.

criteria for judging the composition of fresh (green) forage, particularly in so far as nitrogenous substances are concerned.

The fiber content was usually between 20 and 25 % of the dry matter and tended to increase with the advance of the season. On most dates of sampling, the lowest amounts were found in the samples from the PL plots, but the PN treatments gave about the same results. The unfertilized pasture produced herbage with the greatest percentage of fiber.

The nitrogen-free extract content varied inversely with the nitrogen. The extremes noted were 36 and 50% of the dry matter.

The fat (ether extract) seemed to vary conversely with the nitrogen and inversely with the nitrogen-free extract and fiber. However, the effects of fertilization are not striking.

The proportion of phosphorus in the pasturage was markedly raised by the application of superphosphate, the average increase for both years being about 60%. The addition of lime or potash to the superphosphate treatment was evidently responsible for further small increases in the phosphorus content of the vegetation.

In 11 of 12 comparisons, the addition of potash to the P or PL treatments increased the amount of potassium in the pasturage.

The calcium in the forage was greatly influenced by the prevalence of clover. This plant was by far the most abundant on the PL or PLK plots. The omission of superphosphate resulted in very low calcium contents of Kentucky bluegrass and sweet vernal grasses from the LK plot and these grasses and also clover from the NPK pasture had low percentages of calcium. Superphosphate alone greatly increased the calcium in all three species.

Two groups of treatments resulted in pasturage with high Ca:P ratios, *viz.*, superphosphate omitted, and PL and PLK fertilization. In the first case, the high ratio is due to a very low P content; in the second, to a very high percentage of Ca.

The amounts of Si, Fe, Al, Ca, Mg, Mn, Cl. and S in composited samples from several pastures were determined. On the same pastures, the percentages of Si, Fe, and Al varied widely in the two seasons, probably because of adhering soil. Mg was found to vary consistently with Ca and Mn was uniformly 100% higher in the herbage from unlimed plots. The Cl content of the vegetation was lowest on the unfertilized pastures and was higher on the PK and PLK than on the P and PL pastures. The total S was also low in the unfertilized pasturage and in 1930 was considerably above all others on the PLKNN plot.

THE QUALITY OF ALFALFA SEED AS AFFECTED BY COLOR AND PLUMPNESS[1]

GEORGE STEWART and J. W. CARLSON[2]

An earlier experiment[3] established that there were in the laboratory rather wide differences in the germinating power of alfalfa seed separates of various colors and of different degrees of plumpness. In the first place, it was shown that germination studies on blotting paper gave a considerably higher percentage of sprouts, especially for the discolored fractions, than when the seedlings from the same lot of seed were compelled to penetrate 3/8 inch of sandy loam soil. These differences are briefly summarized in Table 1.

Another experiment with color separates replicated three to five times and the whole repeated seven times showed the effect of the same color and maturity fractions on the percentage of seedling plants which established themselves in the laboratory after coming through 3/8 inch of sandy soil. The results were as follows:

Color fraction	Plants established %
True color	65.1
Light green	58.8
Light brown	53.6
Dark green	45.3
Dark brown	40.5
Shriveled green	24.2
Shriveled brown	18.7

In order to test the value of seed of various color and condition as regards maturity and plumpness, a thorough experiment was undertaken with alfalfa seeds gathered from various growers in the Uintah Basin Such lots of seeds were selected as would give the various color separates desired. The lots were then composited and thoroughly mixed in the grain sampling machine. The various separates were made by hand with considerable care to obtain samples typical of the quality named, no attempt being made to get all of the bulk seed into

[1]Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by Director, July 9, 1931. Received for publication July 13, 1931.

[2]Formerly Agronomist, Utah Agricultural Experiment Station, now Senior Ecologist, Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah, and Assistant Agronomist and Superintendent, Uintah Basin Alfalfa Seed Experiment Farm, respectively.

[3]STEWART, G. Effect of color of seed, of scarification, and of dry heat on the germination of alfalfa seed and of some of its impurities. Jour. Amer. Soc. Agron., 18:743-760. 1926.

the various fractions. About one-fourth of the original bulk sample was previously cut off by the grain sampler and was used as unseparated bulk seed for checks.

TABLE 1.—*Summary of laboratory germination studies on blotters and in soil with alfalfa seeds of various colors and maturity fractions.*

Seed fraction	Germinated on blotters	Germinated in ⅜ inch soil
True color	68.8	59.0
Light green	67.4	33.8
Light brown	67.0	45.2
Dark green	53.0	34.0
Dark brown	40.0	14.6
Shriveled green	25.4	4.4
Shriveled brown	41.8	9.0

About 2 inches of a soil made by mixing loam and sand was placed into long, narrow wooden boxes. Each of these boxes, with holes in the bottom, was set in a metal container. Irrigation was accomplished by keeping water in the metal container. One lot of seed was scarified in a commercial scarifying machine. The seven color separates were made by hand from each lot. At one sowing 50 seeds of each color separate with two unseparated bulk checks were seeded in short rows and covered with 3/8 inch of soil. At the same time a similar sowing was made for the scarified seed, save that none of the check rows were scarified. In all, there were 18 trials, a summary of which is presented in Table 2. Some seeds sprouted but failed to emerge, though no evidence of disease could be seen. These were classified as "weak." Other sprouts, which were attacked by fungi and died, were classified as "moldy."

TABLE 2.—*Percentages of germination of normal and scarified alfalfa seed, together with the relative values of the various color separates compared with unseparated bulk seed (checks = 100).*

Color separate	Total germination		Weak and moldy		Net. healthy and vigorous			
	Normal	Scarified	Normal	Scarified	Normal	Scarified	Mean	Relative
Unseparated check	55.8	54.3	5.0	5.3	50.8	48.9	49.5	100
True color	59.4	75.0	4.0	11.9	55.4	63.2	60.5	122
Light green	49.2	68.4	5.6	15.9	43.6	52.5	49.5	100
Light brown	31.2	46.6	7.6	13.7	23.6	33.9	30.5	62
Dark green	34.8	35.0	8.0	10.8	29.8	24.2	26.1	53
Dark brown	18.2	28.5	3.6	7.7	14.6	21.0	18.9	38
Shriveled green	25.6	27.5	9.8	10.0	15.8	17.5	16.9	34
Shriveled brown	7.6	16.9	1.8	5.3	5.8	11.6	9.7	20
Mean	32.3	42.6	5.3	10.7	26.9	32.0	30.3	61
Relative	100.0	132.0	16.0	35.0	84.0	97.0	94.0	—

The total germination of the scarified seed was appreciably higher than for the unscarified. There were, however, on the average about twice as many weak and moldy sprouts in the scarified lots. There were more total healthy vigorous plants from the scarified seed on account of a considerably higher germination. The relative value of scarified and normal seeds may be listed as follows:

Condition of seedlings	Relative value Normal	Relative value Scarified
Total germination	100	132
Weak and moldy sprouts	16	35
Healthy vigorous plants	84	97

The relative value of the various color separates when compared with checks of which four were grown in each of 18 trials is shown by the following listing:

	Relative value
All checks (unseparated bulk)	100
True color	122
Light green	100
Light brown	62
Dark green	53
Dark brown	38
Shriveled green	34
Shriveled brown	20

Bright true-colored (olive green) seeds were found to be 22% more efficient than ordinary unseparated bulk seeds or than seeds faintly green colored which proved just equal to the bulk. Discolored seed decreased in value until shriveled dark brown seed was only 20% as capable of producing good plants as the bulk seed and only about 15% as capable as the bright true-colored seed separate.

GERMINATION STUDIES IN THE FIELD

In order to find if the color separates gave results in the field similar to those obtained in the laboratory, small field seedings were made. Somewhat less careful sortings of alfalfa seeds had been made into (1) true-colored, (2) plump-discolored, and (3) shriveled discolored separates, no effort being made to separate the green from the brown discolorations. The grade lines were the same as for the laboratory germinated seed separates.

In 1929, plantings were made on June 20, July 8, and July 23, using 1927 seed in one set and 1928 seed in another. In 1930 there was one seeding each with 1927, 1928, and 1929 seed. At each planting there were the three seed separates and the check for each seed

crop used. This made 8 sorts of seed in the 1929 sowings and 12 in the 1930 sowings. At each planting date eight replications of each sort of seed were made. In Table 3 is given a summary of the data obtained in 1929. There were slight differences in the germination when seed from the same lot was sown on different dates, but the really noticeable difference is between the color separates which are 51.2, 29.9, and 16.7% for true-colored, plump-discolored, and shriveled-discolored seeds, respectively, as compared with 42% for the unseparated check seeds. All differences between these color separates and the checks are 8 to 12 times their respective probable errors.

TABLE 3.—*Germination of variously colored alfalfa seed separates sown in the field on three different dates and replicated 14 times in the three sowings combined.**

Color and grade of seed	Year of seed	Planting period	Percentage seeds germinating	Mean of 2 seasons	Relative value on basis of check as 100
Check (unseparated)	1927	June 20	53.0±1.89	42.1±0.79	100.0
		July 8	49.3±2.11		
		July 23	45.2±2.59		
	1928	June 20	40.3±1.17		
		July 8	33.1±2.05		
		July 23	31.9±1.60		
True-color (bright and plump)	1927	June 20	64.2±1.16	51.2±0.79	121.6
		July 8	63.5±2.35		
		July 23	44.4±2.81		
	1928	June 20	53.7±1.71		
		July 8	43.7±1.68		
		July 23	37.9±1.58		
Discolored (plump)	1927	June 20	38.1±1.71	29.9±0.57	71.0
		July 8	31 7±1.52		
		July 23	29.7±1.12		
	1928	June 20	32.4±1.51		
		July 8	25.3±1.25		
		July 23	22 7±1.28		
Discolored (shriveled)	1927	June 20	26.0±1.19	16.7±0.46	39.6
		July 8	22.5±1.82		
		July 23	21.9±1.21		
	1928	June 20	11.5±0.68		
		July 8	9.0±0.85		
		July 23	9.6±0.74		

*The seeding was done in 1929 from seed grown in the two previous years. The relative germinating values are also given by calling the check 100.

In 1930 there was only one seeding date. The data for this year are summarized in Table 4 with the seed crop from which the seed

was taken shown one above the other. The germinations are all slightly lower than in the preceding year and the 1928 seed crop germinated uniformly less than did the other two. The order and the differences are about the same as for the 1929 seedings. The average germination percentages are 39.6 for the check as compared with 46.4, 26.4, and 12.1 for the true-colored, plump-discolored, and shriveled-discolored separates, respectively.

TABLE 4.—*Percentage germination as healthy vigorous plants from the variously colored separates of alfalfa seed.**

Color and grade of seed	Season	Average (10–14) replications germination %	Mean of 3 seasons	Relative value on basis of check as 100
Check (unseparated)	1927 1928 1929	45.1 ±3.42 31.4±1.68 42.5±2.73	39.6±1.56	100.0
True-color	1927 1928 1929	51.6±3.01 36.5±2.12 51.3±3.02	46.4±1.58	117.1
Discolored (plump)	1927 1928 1929	24.2±1.63 19.5±1.37 35.5±1.99	26.4±0.97	66.6
Discolored (shriveled)	1927 1928 1929	18.0±1.46 7.5±0.79 10.8±1.00	12.1±0.64	30.5

*One sowing was made in the spring of 1930 from seed grown in the three preceding years. The relative ability of each color separate to establish plants is shown when the checks are called 100.

Owing to the fact that there was seeding at only one date during 1930 the probable errors are larger, but the differences between the separates are still 10 times their probable errors. The differences, however, between the checks and the true-colored seed is about three times the error and the difference between the plump-discolored seeds and checks about seven times the error.

Since the laboratory tests had shown a rather high percentage of weak or moldy sprouts, data were also taken in the field on the difference in the percentage of germination and the percentage of plants established. Table 5 summarizes these data and shows that from 16 to 32% of the germinated seedlings died before establishing themselves in the field. This figure may be noted by observing the difference between 100 and the percentage of germinated sprouts which grew into plants.

The laboratory tests and the field tests are compared in Table 6.

As might be expected there was a lower percentage of seeds germinating in the field than in the laboratory. There is a difference of from 55.1 to 40.9% for the unseparated check seed and from 67.2 to 48.8% for the true-colored separates.

TABLE 5.—*Percentage of the germinated seeds which establish themselves as healthy vigorous plants, together with the relative value of the various color separates, based in one case on the germinating quality and in the second case on the seedlings which grew and established themselves.*

Color and grade of seed	Year in which seed was grown	Percentage of germinated sprouts which grew		Relative value, check = 100	
		Average by seed crop	Grand average	Based on germination	Based on seedlings which grew
		Sowings of 1929			
Check	1927 1928	81.8 85.0	83.4	100.0	100.0
True-color	1927 1928	86.0 83.2	84.6	128.3	133.7
Discolored (plump)	1927 1928	81.3 75.1	78.2	72.9	66.3
Discolored (shriveled)	1927 1928	75.8 78.7	77.3	37.5	34.8
		Sowings of 1930			
Check	1927 1928 1929	77.3 79.6 80.5	79.1	100.0	100.0
True-color	1927 1928 1929	76.5 77.8 77.1	77.1	117.0	114.1
Discolored (plump)	1927 1928 1929	83.0 77.9 73.2	78.0	66.9	65.7
Discolored (shriveled)	1927 1928 1929	69.4 64.0 72.2	68.6	29.6	25.9

It is noteworthy, however, that 75% of the plump discolored seeds which germinated in the field established themselves as healthy plants as compared with an average of about 64% in the laboratory.

It is to be emphasized, therefore, that in the field germination was about 15% lower than in the laboratory. About 75 to 80% of the seeds which germinated in the field became strong healthy plants. This percentage of establishment was approximately the same irrespective of the color of the seeds.

TABLE 6.—*Comparative germination, plant establishment, and relative value of variously colored seed separates when tested in the laboratory and in the field.**

Color and grade of seed	Germination		Plants which grew		Relative value, checks = 100	
	Lab.	Field	Lab.	Field	Lab.	Field
Check	55.1	40.9	49.5	34.3	100	100
True-color	67.2	48.8	60.5	47.3	122	138
Light green	58.8	28.1	49.5	25.7	100	75
Light brown	38.9		30.5		62	
Plump:						
Dark green	34.9		26.1		53	
Dark brown	23.4		18.9		38	
Shriveled:						
Dark green	26.6	14.4	16.9	11.2	34	33
Dark brown	12.3		9.7		20	

*The seeds used in the field tests were not graded into so many color classes and these were broader classes as indicated by the brackets.

EFFECT OF TIME AND METHOD OF HARVESTING ON COLOR AND PLUMPNESS OF ALFALFA SEED

In the Uintah Basin alfalfa left for seed is usually cut when about two-thirds of the seedpods are black or brown. When cutting is delayed beyond this period, much of the seed is often lost by shattering. When early frosts threaten, some growers believe that some injury is avoided by cutting earlier than at the stage of maturity mentioned, leaving the stems containing the seedpods stacked for some time before threshing. To determine the effects on the quality of seed of early cutting and stacking as compared with cutting at the usual time, an experiment was conducted during 1929 and 1930.

On five sets of plats, each replicated three times, first-growth alfalfa was used for seed production. When approximately one-third of the seedpods were black or brown, as determined from counts of random samples, the crops on the first set were cut and stacked when the leaves and stems became sufficiently dry. The crops on the second and third sets were cut when approximately one-half of the pods were ripe. The crop from one of these sets was stacked, while that from the other was threshed as soon as the stems and leaves were dry. The crops on the remaining sets received similar treatment after being cut at the usual time. It was thought that perhaps stacking would prevent a too-rapid drying of the stems and leaves, thereby allowing the immature seeds to continue to draw moisture and nourishment to complete normal maturity.

After threshing, representative samples of seed from each of the plats were studied and worked into three classes, based on color and condition. Seed which was plump and of a bright yellow or olive-

green color represented true-color seed. That which was distinctly green or brown in color but plump constituted a second class. Shriveled seed which was also distinctly green or brown in color comprised the third class. Table 7 gives the percentages of seed of each color class. The averages for the 2-year period show that the differences in the seed obtained from the various treatments are not large. A slightly lower percentage of true-colored seed was obtained from the plats harvested when one-third of the pods were ripe. For this treatment, a slightly higher percentage of shriveled-discolored seed is also shown. Since the quality of the seeds was determined from samples which had been threshed and re-cleaned under ordinary commercial methods, it is possible that the plats cut early produced considerably more shriveled and discolored seed than is actually shown in the percentage data. Seed of this type is relatively light and is easily blown out in the threshing and re-cleaning operations. Since its value as commercial seed was the point of investigation, no attempt was made to secure accurate yield data on the plats harvested at various times.

TABLE 7.—*Average percentages of true-colored (olive green) seed and of plump and shriveled discolored green or brown seed from alfalfa harvested at different stages of maturity of the seed and threshed as soon as sufficiently dry or stacked for a period of a few weeks before threshing.*

Sample No.	Treatment	Year	Quality and condition of seed					
			True color		Plump discolored		Shriveled discolored	
			%	Mean	%	Mean	%	Mean
1	Cut when one-third of pods were ripe and stacked	1929	77.6		12.2		9.7	
		1930	74.6	76.1	7.6	9.9	18.6	14.1
2	Cut when one-half of pods were ripe and stacked	1929	77.6		12.0		9.3	
		1930	82.6	80.1	7.6	9.8	9.6	9.4
3	Cut when one-half of pods were ripe and threshed	1929	74.5		15.8		12.6	
		1930	78.3	76.4	12.6	14.2	9.0	10.8
4	Cut at usual time and stacked	1929	81.0		8.6		9.5	
		1930	83.5	82.2	7.5	8.0	9.2	9.3
5	Cut and threshed at usual time	1929	81.8		7.8		9.7	
		1930	83.0	82.4	4.1	5.9	12.0	10.8

Table 8 gives data which indicate the effects of different clippings, cultivation, and irrigation treatments of alfalfa for seed production in relation to the quality of seed produced. The average of the

analysis of seed taken from each plat for a 4-year period shows small differences in the percentage of true-color seed, except in the case of late clipping. A decrease in percentage of true-colored seed with a corresponding increase in shriveled-discolored seed may be expected for these treatments, due to a shortened season in which an insufficient time is allowed for the seed to develop to normal maturity. In the case of the remaining treatments the differences are probably too small to be important in commercial seed.

TABLE 8.—*Effect upon quality of alfalfa seed of clipping the first growth at various stages, of irrigation at different times when other conditions for growth are the same, and of different types of cultivation applied in the spring.*

Sample	Treatment	Average quality and condition of seed for 4-year period		
		True color %	Plump discolored %	Shriveled discolored %
	Clipping First Growth			
1	When 6 inches high	75.7	12.3	12.0
2	10 days after No. 1	77.8	11 8	9 6
3	In bud stage	74.8	14 8	10.4
4	At beginning of bloom	69.0	17 3	12.9
5	At 1/10th bloom	61.4	17.5	21.0
6	At full bloom	50.5	21.6	27.3
7	Sheep-off early	79.8	9.6	11.4
8	Sheep-off late	77.5	11.9	10.5
9	No clipping (check)	78.6	12.0	9 8
	Cultivation			
1	None (let weeds go)	77.2	14.4	8.4
2	None (hoe for weeds)	80.6	11.0	8.3
3	Heavy discing	73.0	18.0	8.9
4	Both ways once	72.8	16.9	10.0
5	Row cultivation	77 6	12.1	10.2
6	One way once (check)	73.0	17.1	10.2
	Time of Irrigating			
1	One in fall	74.3	16.5	9.1
2	One in early spring	78.4	12.8	9.4
3	Early spring and when pods form	70.3	16.2	13.1
4	One before clipping	75.5	14.6	9.7
5	One after clipping	74.8	14.1	11.4
6	One at full bloom	77.7	13.2	9.0
7	When pods form	78.9	11.5	9.4
8	None	81.5	10.4	7.7
9	None (check)	79.3	11.2	9.3

From these studies it appears that stacking, while it has many advantages in the way of protecting the seed from rain and from excessive drying which results in shattering, probably cannot be expected to improve greatly the quality of the seed cut in an extremely immature condition. It also appears that quality in alfalfa

seed varies more with the season than it does as a result of differences in the ordinary production methods used in the Uintah Basin, Utah.

SUMMARY

Laboratory studies have established that there is a considerably higher germination of alfalfa seeds on blotters than occurs in soil in the laboratory as measured by emergence through 3/8 inch of sandy loam soil.

When germinated in soil there was progressively poorer germination for greater and greater degrees of discoloration in the seed. Bright olive green seeds were highest with an average of 65.1%, whereas shriveled brown seeds were poorest with a germination of 18.7%.

Scarification increased the total germination about 10 to 15%, but affected the brighter colored seeds the most. However, there was a total of 10.7% weak and moldy sprouts from scarified seeds as compared with 5.3% from unscarified.

Tests conducted in the field repeated the laboratory tests except that instead of seven color separates used in the laboratory only three were used in the field. The color separates for field seeding were so made as to compare with the laboratory separates. Germinations in the field as measured by emergence were considerably lower in the field than under laboratory conditions when seeded at about the same depth. Bright plump seeds gave 67.2% in the laboratory and 48.8% under field conditions. From 75 to 80% of the plants which emerged in the field established themselves and grew for some weeks. Bright-colored seeds were found to be 38% more effective in the field than were bulk (check) seeds from the same lot, while in the laboratory the difference was 22%.

Field plat experiments devoted to seed production also yielded valuable data regarding the percentages of discolored seeds produced. Significant increases in discolored seeds were found in the seeds produced from plats on which the seed crop was allowed to start late. This was accomplished by growing a hay crop before the growth from which seed was to be taken was allowed to start. The manner of harvest, the nature of field tillage, the sort of irrigation treatment, or the time of clipping the preceding growth (save for over-late clipping), all produced seed of the same color within the limits of error variations.

THE USE OF THE ANTIMONY ELECTRODE FOR DETERMINING THE pH VALUE OF SOILS[1]

E. E. BARNES and R. H. SIMON[2]

Within agronomic circles the pH value of soils has assumed great importance in the past decade. Perhaps no one thing has done more to bring about this condition than the somewhat general use of the quinhydrone electrode introduced by Bijlmann (1)[3]. The use of this electrode as a substitute for the hydrogen electrode has done much to make the determination of pH value a simple and rapid laboratory procedure. On some soils the quinhydrone electrode does not work satisfactorily because the potential drifts rapidly. On such soils some other type of electrode must be used. Occasionally, also, it is desirable to measure the pH value of a soil suspension without the addition of any chemical. In such cases the quinhydrone electrode is not suitable.

The antimony electrode has been proposed as a substitute, and has been described by a number of investigators (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13). However, it has never come into general use, possibly because of the variance in the equations which have been proposed to compute the pH value from the potential registered.

The authors being desirous of testing on successive dates some soil suspensions which were available in only small amounts became interested in the possibilities of the antimony electrode. This paper describes work done in establishing equations for computing the pH value from the difference in potential between the antimony electrode and a saturated calomel half cell.

For the purpose of this investigation, standard buffer solutions were prepared according to the directions of Clark and Lubs, covering a range between 1.4 and 11.4 pH. The theoretical value for the difference in potential between a hydrogen electrode and a saturated calomel half cell was calculated for each of these solutions and in this paper these values are designated as V_H. The value for the difference in the potential between the antimony electrode and a calomel half cell was determined experimentally for each of the solutions. These values have been designated V_{Sb}. Table 1 gives the theoretical pH value for each of the buffer solutions prepared, the experimentally determined antimony electrode potentials, the calculated hydrogen

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication July 20, 1931.

[2]Associate Agronomist and Assistant in Agronomy, respectively.

[3]Reference by number is to "Literature Cited," p. 161.

electrode potentials, and the arithmetic difference between the values V_H and V_{Sb}.

It will be noted that the difference between the values V_H and V_{Sb} is constant between pH 1.4 and pH 6.4 and that this difference is 0.263 volt. From pH 6.8 to pH 8.8 this difference is an increasing series, the different values being a linear function of the pH values. From pH 9.2 to pH 11.36 the differences between V_H and V_{Sb} are again quite constant and average 0.290 volt.

The values of V_H in terms of V_{Sb} are, therefore, as follows:

$V_H = V_{Sb} + 0.263$ for the range pH 1.4 to pH 6.4
$V_H = V_{Sb} + 0.01286\,(\text{pH} - 6.7) + 0.263$ for the range pH 6.8 to pH 8.8
$V_H = V_{Sb} + 0.290$ for the range pH 8.8 to pH 11.4

It is evident, therefore, that three different equations are needed for computing pH values from the V_{Sb} values over the range in pH values from 1.4 to 11.4 pH.

Taking the equation used for computing pH values from differences of potential between a hydrogen electrode and a saturated calomel half cell as

$$\text{pH} = \frac{V_H - 0.2464}{0.059}$$

and substituting for V_H its equivalents in V_{Sb}, one obtains three equations which are each applicable over their appropriate range of pH values. Thus, for the first range from pH 1.4 to pH 6.6, the appropriate equation for the antimony electrode is

$\text{pH} = \frac{V_{Sb}}{0.059} + 0.28$; for the range from pH 6.6 to pH 8.8,

$\text{pH} = \frac{V_{Sb}}{0.04625} - 1.51$; and for the range of pH 8.8 to 11.4,

$$\text{pH} = \frac{V_{Sb}}{0.059} + 0.74.$$

In measuring the pH value of soils with the antimony electrode the following procedure is recommended: The soil should be mixed with an equal weight of water and well shaken, then allowed to stand a few minutes. The antimony electrode and the agar bridge from the calomel half cell should then be buried in the mud at the bottom of the tube and the potential measured. The tube should then be rotated and after about 10 seconds the potential should again be measured. If the same potential is obtained with both readings, this should be used. If the potential is different on the second reading,

the tube should again be rotated and after waiting about 10 seconds the potential should again be read. This procedure should be repeated until two successive readings are alike. If desired the tube may again be rotated and after about 10 seconds the potential should read the same as the previous reading. Rotating the tube momentarily throws the system out of balance, but it quickly returns to the former reading if a constant potential has been reached.

TABLE 1.—*Difference in the voltage obtained with the antimony electrode as compared with calculated voltage of hydrogen electrode in standard buffer solutions.*

pH	V_{Sb}	V_H (calculated)	$V_H - V_{Sb}$
1.40	0.068	0.329	0.261
1.80	0.079	0.343	0.263
2.20	0.111	0.376	0.265
2.40	0.125	0.388	0.263
2.60	0.136	0.399	0.263
2.80	0.149	0.412	0.263
3.00	0.160	0.424	0.264
3.40	0.182	0.447	0.265
3.60	0.196	0.459	0.263
3.80	0.207	0.471	0.264
4.00	0.221	0.483	0.262
4.60	0.258	0.518	0.260
5.00	0.281	0.542	0.261
5.60	0.314	0.577	0.263
6.00	0.336	0.601	0.265
6.40	0.360	0.625	0.265
Average..........	—	—	0.263
6.80	0.379	0.647	0.266
7.00	0.393	0.660	0.267
7.60	0.423	0.696	0.273
8.00	0.438	0.719	0.281
8.40	0.457	0.743	0.286
8.80	0.477	0.767	0.290
9.20	0.500	0.790	0.290
9.60	0.521	0.815	0.294
10.00	0.544	0.838	0.294
10.17	0.557	0.846	0.289
10.35	0.569	0.857	0.288
10.55	0.581	0.868	0.287
10.86	0.599	0.886	0.287
11.04	0.609	0.897	0.288
11.36	0.627	0.916	0.289
Average...........	—	—	0.290

A comparison of the pH values obtained by means of the antimony electrode with those obtained with the quinhydrone electrode has been made on 100 samples of Canfield silt loam whose reactions varied from as low as pH 4.7 to as high as pH 7.6. The very low reactions were obtained by additions of aluminium sulfate to the soils in the field

and the high reactions were reached by the application of limestone in the field. The agreement of the pH values obtained by the two electrodes was within 0.1 pH in the case of 70 out of the 100 samples. In the case of the 30 samples out of the 100 where the agreement was not

TABLE 2.—*The pH values as determined by different methods.*

Plat No.	pHSb	pHQu	pH (colorimetric)
	Range pH 4.5		
6 N	4.84	4.94	4.8
8 N	4.75	4.74	4.8
10 N	4.96	5.06	5.0
	Range pH 5.0		
2 N	4.98	5.09	5.0
1 S	5.28	5.39	5.2
6 S	5.12	4.97	5.0
	Range pH 6.0		
1 N	6.02	6.12	6.0
2 N	5.44	5.56	5.4
5 N	5.50	5.63	5.5
7 N	5.85	6.03	5.7
9 N	5.66	5.82	5.6
10 N	5.66	5.80	5.7
8 S	5.90	6.00	5.8
10 S	5.78	5.93	5.7
	Range pH 7.0		
3 N	6.78	6.90	6.6
3 S	6.69	6.86	6.8
4 S	6.51	6.72	6.6
5 S	6.46	6.62	6.4
7 S	6.60	6.73	6.6
8 S	6.55	6.77	6.8
9 S	6.89	7.01	7.0
	Range pH 8.0		
2 N	7.24	7.34	7.2
3 N	7.16	7.05	7.0
4 N	7.16	7.00	7.0
6 N	7.26	7.40	7.3
8 N	7.25	7.14	7.2
9 N	7.46	7.33	7.2

within 0.1 pH the reaction was determined colorimetically by means of a B. D. H. Capillator. Table 2 shows the pH values of these 30 samples as determined by the three methods. It is noteworthy that in 15 of the 17 cases where the reaction is acid, the agreement between the antimony electrode result and the colorimetric result is better than between the quinhydrone electrode result and the colorimetric result. In 7 out of the 13 cases where the reaction is alkaline the agreement between the antimony electrode result and the colorimetric

result is better than between the quinhydrone electrode and the colorimetric result. This would seem to indicate that over this range of reaction the antimony electrode is at least as reliable as the quinhydrone electrode.

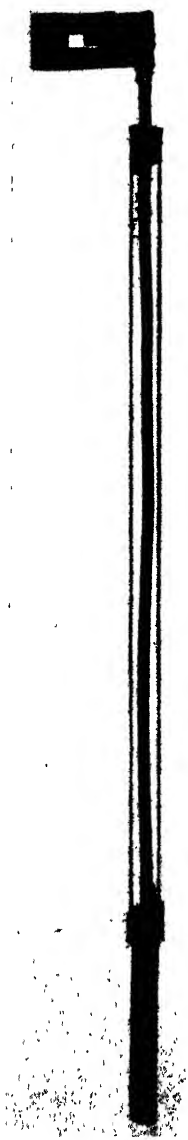

Fig. 1.—The form of antimony electrode used in this work.

In the case of certain soils high in manganese a rapid drift of the potential results when the quinhydrone electrode is used. This fact has been noted by several investigators. The antimony electrode gives constant potentials with all such soils tested by the authors. On such a soil from the Greenville Experiment Station Farm of Kentucky the following results were obtained:

	pH_{Sb}	pH_{Qu}	pH (colorimetric)
After 1 minute..	5.53	5.84	5.5
After 5 minutes...	5.53	6.90	5.5

The antimony electrode gave results in good agreement with the colorimetric method and gave constant results over a 5-minute period, while the quinhydrone electrode gave too high results even in the first reading.

On a soil obtained from Hawaii, which showed by colorimetric test to have a reaction of 5.5 pH, the same value was obtained with the antimony electrode, while with the quinhydrone electrode the first potential balance that could be obtained indicated a pH of 7.0 and rapidly increased with time.

Our experience has been that the antimony electrode does not work well in the presence of large quantities of hydroxy acids, such as citric, tartaric, and malic, and at least some of the amino acids when present in large quantities affect its accuracy. Soils, however, seldom if ever contain these substances in sufficient quantities to affect the accuracy of the determination.

It would seem that the antimony electrode furnishes another tool for determining the reaction of various substances including soils. It works well in determining the reaction of milk, urine, agar, and silicic acid gels.

The antimony electrodes used in this work (Fig. 1) were cast from C. P. antimony by drawing some of the molten metal up into a pyrex glass tube. As soon as the metal had solidified the glass tube was sprinkled with cold water. This caused the glass to break into small pieces and made removal easy. The resulting antimony rod was trimmed up on the ends into the shape of a cylinder and a piece of copper wire was soldered on the end. The wire and the end of the antimony rod were then inserted into a piece of pyrex tubing of the same size as that used for a mold and cemented in with DeKhotinski cement in such a manner that about an inch of the antimony rod projected from the end of the tube and the copper wire extended out through the other end of the glass tube. If the electrode has stood for some time since being used, it is always wise to check it against a buffer solution of known pH value before using it. If it does not give the correct potential for the solution, it will likely be too high. The authors have found the following procedure sufficient to adjust the electrode: The antimony which projects from the glass rod is sandpapered with No. 00 sand paper until it is bright. It is then heated gently in the blue flame of an alcohol torch until it is coated with oxide. It should then be checked again in the standard buffer solution and if it is too low in potential it should be heated again. Should too much oxide be formed so that the electrode gives too high a potential, it should be lightly sandpapered.

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BOOK REVIEWS

INTRODUCTION TO AGRICULTURAL BIOCHEMISTRY

By R. Adams Dutcher and Dennis E. Haley, New York: John Wiley & Sons, Inc., 484 pages, illus. 1932. $4.50.

It is the impression of the reviewer that the title of this book describes its contents less accurately than does the authors' statement in the preface that it is their hope that it may be useful "as a general reference book for all readers who are interested in the part that chemistry has played in the development of agricultural science." For example, several of the chapters, dealing with "The Soil," "Fertilizers," "Insecticides and Fungicides," "Mineral Nutrients," etc., are presented more largely from the farm practice than the "biochemical" standpoint. The senior author's own major interest is reflected in the unusually extensive treatment of the biochemical basis for animal and human nutrition.

The book is divided into three parts dealing respectively with "General and Introductory" discussions of the chemistry of living matter; "The Plant," chiefly from the nutritional point of view; and "The Animal," again chiefly from the nutritional standpoint. The material presented is accurately stated, up-to-date, and well-chosen. It is excellently illustrated, an unusual feature being the large number of pictures of prominent chemists who have contributed to the agricultural applications of this science.

It is the opinion of the reviewer that this book is by far the best that is available in its field and is destined to be widely used as a text and reference. (R. W. T.)

CROP PRODUCTION AND MANAGEMENT

By J. F. Cox, New York: John Wiley & Sons, Inc., Ed. 2. XII + 469 pages, illus. 1930. $2.75.

The present book is a revision of a former one by the same author entitled "Crop Production and Soil Management." Because the series in which this book is published now contains a soil treatise, the edition under discussion does not deal with soils in detail, and becomes essentially a crop text with only such treatment of soil essentials as is necessary to provide for a reasonably well rounded out discussion of field crop growing.

The introductory portion consists of four chapters which treat of major considerations in crop growing, such as the choosing of crops adapted to prevailing conditions, general soil preparation, and maintaining and increasing fertility. The crop section proper consists of three parts, *viz.*, grain crops, legumes and grasses, and the more intensive or cash crops, such as potatoes, beans, sugar beets, and others. In fact all the important field crops of the northern and eastern United States are discussed with a fair degree of fullness and the detail is in proportion to their general importance.

The concluding sections of the book deal with the importance of well-planned rotations, weed and crop pest control, school and community crop exhibits and crop judging contests, and crop studies for the field and classroom.

The treatment of rotation principles is good and the importance of good rotation practices is repeatedly emphasized in the discussion of the individual crops. As the subject of rotations is important it is refreshing to find a book of the type of the one being considered giving this matter somewhere near the attention it deserves.

The class exercises provided and the community surveys and field studies suggested at the close of each chapter of the text should help to make the book very useful in the class room, particularly in the agricultural departments of high schools. The book also contains an appendix in which much valuable matter is compactly presented. Tables for measuring hay, grain, and silage, and statements in tabular form of recommended crop varieties the amount of seed used to the acre, and similar material are included.

The book should well serve the purpose for which it was written for the author says "it is intended as a handbook for students of crop production and management problems whether they are enrolled in a vocational school or college or at work in a farming occupation." (J. H. B.)

THE WASTE PRODUCTS OF AGRICULTURE — THEIR UTILIZATION AS HUMUS

By Albert Howard and Yeshwant D. Wad. London: Oxford University Press. XIV + 167 pages, illus. 1931.

As may be inferred from its title, this latest book on Indian agriculture deals with the utilization of organic by-products in the main-

tenance of the soil humus. During 26 years spent in the study of crop production in India the senior author has not only investigated the conversion of all sorts of animal and plant wastes into humus, but also has devised a humifying process simple enough for the Indian cultivator. The Indore process, as it is called, is described in detail in the volume under review.

The introductory chapter of the book consists of a comparison of the Occidental and Oriental systems of agriculture in which the weaknesses and problems of the Indian methods are stressed. The maintenance of soil organic matter seems especially difficult in tropical soils. The two chapters that follow concern themselves with the relationships between organic matter and soil fertility and with the sources of organic matter especially in the Orient. Chapters IV and V, covering 49 pages, deal with the minutiae of the Indore method. The last chapter, which is very brief, discusses the possible application of the process to other regions. Most of the chapters are followed by a well chosen bibliography.

The Indore process is a scientifically controlled composting by which all sorts of agricultural wastes are reduced to a humus of relatively high nitrogen content. The nitrogen-carbon ratio and the moisture content of the mixture are properly regulated and the process is comparatively sanitary at every stage. Plant residues, fresh dung, urine earth, wood ashes, and stable sweepings are utilized. The proper fermentation is obtained by means of bacterial and fungal inoculants and by timely turning. The final product is considered as three times more valuable than farm manure.

According to the authors, the method can be used essentially as outlined any place in the tropics and sub-tropics, sanitary benefits being one of the important reasons for its adoption. As to its use unmodified in Canada, the United States, and Great Britain less confidence is expressed.

To those interested in Indian agriculture as well as in composting the appendix, consisting of 48 pages of fine print, is worthy of attention. The manurial problems of India, as well as some aspects of soil improvement, are presented in more or less detail. The Indore Institute and its organization also receive attention, especial emphasis being placed on the management there of India labor. (H. O. B.)

THE BOTANY OF CROP PLANTS

By Wilfred W. Robbins. Philadelphia: P. Blakiston's Son & Co. Inc. Ed. 3, revised. X + 639 pages, illus. 1931. $4.

This third edition of this always useful text appears in a new form. A page ¾ in. longer and ¼ in. wider presents a much better appearance than the smaller page of previous editions, and reduces the thickness of the volume considerably. A new chapter on Palms has been added and a number of more useful illustrations have replaced the production charts formerly used.

A few chapters have been pretty thoroughly revised and a number of additions made to the bibliographies. It would seem that the

bibliographies in general might have had a more thorough overhauling and more of the later papers cited. A consistent error of "V. P." in place of U. P. Hedrick catches the reviewer's eye, and the omission of *Brassica chinensis* and *B. pekinensis* from the key to species of *Brassica* seems unwarranted. There are a few other slips denoting a not too careful proof reading, but it is perhaps a bit finicky to call attention to minor errors such as these in a book which is on the whole admirably put up and certainly indispensable for any type of class work on cultivated plants, as well as for general handy reference for the numerous workers in various phases of plant study, such as plant breeding, soils investigations, variety trials, etc. (G. P. V. E.)

AGRONOMIC AFFAIRS

RUBBER PLANTS IN NORTH AMERICA

According to J. W. Pincus, consulting agriculturist of New York City, an interesting bulletin under the above heading has been written in Russian by Professor N. I. Vavilov, Director of the Lenin Agricultural Academy and Soviet Plant Institute of the Lenin Academy.

Professor Vavilov spent several months in 1930 in the United States and Mexico and while here devoted considerable time to studying various rubber-producing plants, among them the guayule which is grown commercially in California.

In addition, he gives a brief description of the work of Edison with Solidago and of the work of the Department of Agriculture with rubber-bearing plants. The publication is well illustrated by photographs taken by Professor Vavilov.

NEWS ITEMS

At the last meeting in December of the Iowa Section of the American Society of Agronomy the following officers were elected for the ensuing year: *President,* Dr. E. R. Henson; *Vice-president,* Dr. F. B. Smith; *Secretary-treasurer,* Professor J. C. Eldridge. In arranging the program for the year two symposia have been planned; one on the role of organic matter in the soil, the other on the absorption and utilization of plant nutrients by the plant.

At the recent meeting of the American Association for the Advancement of Science at New Orleans, Dr. P. E. Brown of Iowa State College was elected Secretary of the Secretaries' Conference for the ensuing year.

Owing to the fact that he will be absent on sabbatic leave for a large part of the year, Dr. T. L. Lyon has found it necessary to decline the chairmanship of the Nitrogen Research Award Committee of the Society. President P. E. Brown has appointed Dr. M. M. McCool as chairman of the committee in Dr. Lyon's place.

Through the kindness of H. A. Huscke of the National Lime Association, complete stenographic notes were obtained on the discussion of papers presented at the calcium-magnesium symposium held in connection with the last annual meeting of the Society. Dr. A. B. Beaumont of Massachusetts State College

has a copy of these notes, together with copies of the discussion papers, on file. Those desiring copies of notes or papers may obtain same by writing for them and paying cost of copying.

DR. JOHN H. PARKER, Professor of Agronomy at Kansas State Agricultural College and for the current academic year a member of the Department of Plant Breeding at Cornell University, addressed the Staff of the New York State Experiment Station at Geneva recently on the subject of "Breeding Plants for Resistance to Diseases and Insects."

ORR M. ALLYN, formerly a member of the Agronomy staff at the University of Illinois, died after a very short illness on October 27, 1931, at Lewiston, Montana. While at the University of Illinois, Mr. Allyn specialized in crop production. Later he took up the work of Farm Adviser in which capacity he served in two counties. Mr. Allyn was a capable, energetic worker, a man of estimable character, and one highly esteemed. In his passing the loss of a most valuable citizen is sustained.

DR. P. S. BURGESS, formerly Professor of Agricultural Chemistry, University of Arizona, has been named Dean of the College of Agriculture and Director of the Experiment Station at Tucson.

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A STUDY OF SOIL STRUCTURE[1]

R. E. STEPHENSON and A. R. MARQUARDT[2]

The productive value of soils is more dependent upon structural characteristics than upon any other property. This is especially true because soil structure cannot be modified for improvement in any practical way beyond certain very narrow limits.

Soil structure is defined as the arrangement of particles in contradistinction to texture, which is determined by the size of the ultimate soil grain. Texture is an important factor but by no means a controlling factor in soil structure. Clay is associated with compact, close, undesirable structures. Yet the laterites which are often abnormally high in clay are among the most friable soils to be found. Bennett and Allison (6)[3] report soils in Cuba with 85 to 90% of colloidal matter and describe them as especially friable and tillable.

Table 1 presents data indicating the lack of correlation between field behavior and water permeability with content of clay and colloidal matter. Two of the soils are from Bennett and Allison's data on the soils of Cuba (6).

Organic matter is helpful to soil structure, yet tropical soils with very little humus are often more tillable than the high-humus soils of the cool temperate zones.

Soil structure, therefore, is extremely impressive in its significance, and yet rather elusive of explanation. The results of a good or a bad structure are exasperatingly prominent, and yet no method has yet been devised for measuring structure, or for expressing structure in any sort of numerical terms.

[1]Contribution from the Department of Soils, Oregon State Agricultural College, Corvallis, Oregon. Published as Technical Paper No. 153 with the approval of the Director of the Oregon Agricultural Experiment Station. Received for publication July 18, 1931.

[2]Associate Professor of soils and graduate student in soils, respectively.

[3]Reference by number is to "Literature Cited," p. 181.

Bouyoucos (9) states that soils have an ultimate or natural structure which is easily obtained, simply by allowing the thoroughly dried soil to slake in water. It is easily demonstrated that different soil types may slake with particles of different and more or less characteristic shapes and sizes.

TABLE 1.—*Field behavior and water permeability of soils*

Location	Soil type	Clay %	Field behavior	Water permeability
Cuba...	Matanzas clay	82–91	Somewhat granular, moderately plastic	Freely permeable, decided porosity
Cuba. .	Yaguajay clay	66–82	Fragmental, very plastic	Drainage poor
Oregon. .	Meyer clay adobe	38-45	No granulation, very plastic	Drainage very poor
Oregon. .	Aiken clay	58–88	Excellent granulation, moderately plastic	Water permeability 10 times that of Meyer, drainage excellent

Bouyoucos (9) states further that the soil structure observed in the field is artificially produced. It is this artificial structure that is of most interest in practical soil management. Great importance lies in the evaluation of the soil factors which make it possible to maintain a desired structure in one soil and practically impossible to produce an even passably satisfactory structure from another. It should be possible to discover the factors which govern soil structure, and through this knowledge, to use the natural structure of the soil in the most advantageous manner.

MEASURING SOIL STRUCTURE

The studies reported here include work upon soil samples taken in the Willamette Valley where rainfall averages 40 inches a year. The Valley soils consist of the Cove series, a very heavy tight soil, and the Dayton series, which has a very refractory subsoil, an Aiken soil from a forested area, and an Aiken soil from an unforested area, the latter taken in the A, B, and C horizons Another group of soils was taken from southern Oregon in the Medford area,[4] where the rainfall averages about 18 inches. The Meyer and the Coker series are both very troublesome in the pear-growing sections, where a high water table is present during part or all of the year (13). The soils are

[4]The Medford soil samples were supplied by Mr. Arch Work and Mr. M. R. Lewis, who are in charge of irrigation investigations in that area.

troublesome regardless of water table, however, and are not only difficult to drain but water penetration in irrigation is difficult and slow. The Medford series is not so refractory as the other two, yet it cannot be described as a soil of good structure.

Physical and chemical data as here reported were obtained for the purpose of securing information on the various factors which may affect soil structure. The permeability of the soils to water was given particular attention because of its close relation to the field problem. The Bouyoucos method (8) was used with a manometer inserted so that the suction pressure was under control. The pressure employed varied from 65 to 67 cm, or averaged about 0.87 of an atmosphere. These variations had little effect upon the rate of percolation of water through the soils. Slater and Byers (19) report a method for field percolation rates in soils. No field data have yet been obtained on these soils, however.

The plasticity indices were determined by the procedure reported by Russell and Wehr (18). The Bureau of Soils water vapor absorption method (17) was used for the quantitative determination of soil colloids. The colloidal material was separated from the soil for study by the process of sedimentation, using sedimentation periods based upon Stoke's law. Exchangeable calcium was determined by replacing with ammonium acetate. Hydrogen was replaced with neutral N/10 calcium acetate and titrated. The total exchangeable base of the soils was determined by the method of Bray and Wilhite (10) The exchange capacity was obtained from the sum of the exchangeable bases and the exchangeable hydrogen.

There are no standards of perfection for soil structures. Lyon and Buckman (14) recognize three general structures, *viz.*, single grain, crumb, and puddled. The soil morphologist recognizes many different structural arrangements of soil particles which are significant from the standpoint of morphology and classification of soils, but many of which have little value from the agricultural point of view.

Christensen (12) has given mathematical expression to friability in what he designates as the friability index. Friability and soil structure are undoubtedly closely related and it is to be hoped that this line of attack may prove fruitful of results. The present authors have not given the method any study, however.

In the past plasticity indices have received considerable attention (7, 18). In this study the plasticity index correlates as well with the established field behavior of the soils as any measurement made. The Aiken soil, which is well-drained, pulverulent, and friable in tillage and yet of good moisture capacity, shows a very low plastic index.

That is, the soil has those physical properties and characteristics reported for lateritic soils.

TABLE 2.—*The plasticity, shrinkage, and field behavior of the soils investigated.*

Soil type and horizon	Lower plastic limit	Upper plastic limit	Plasticity number	Shrinkage coefficient	Field behavior
Aiken clay, A. . .	32.9	33.8	0.9	7.19	Well drained, pulverulent, friable
Aiken forest, A .	40.2	46.2	6.0	9.40	Well drained, pulverulent, friable
Medford gravelly clay loam, B .	16.8	26.6	9.8	8.13	Fair drainage, slightly friable, and pulverulent
Dayton silty clay subsoil, B	21.8	38.0	16.2	11.91	Very plastic, no granulation, impermeable to water
Cove clay subsoil, B	20.0	36.0	16.0	11.20	Very plastic, heavy, compact, poor drainage
Meyer clay adobe, A.	18.0	33.9	15.9	11.56	Plastic and run together, no granulation, impermeable
Coker clay adobe, A	19.1	48.9	29.8	11.56	Very plastic, not granulated, poorly drained

In contrast to the desirable structure of this Aiken soil is the very refractory structure of the Dayton subsoil, Cove clay subsoil, and both the Meyer and Coker soils.

The shrinkage coefficients do not exhibit wide enough variations to have a great significance (Table 2). The better soils, from the standpoint of field behavior, however, show the lowest shrinkage coefficient.

The permeability measurement, if it correlates sufficiently closely with field behavior, should be of great value where problems of drainage or irrigation are involved. A study of the data presented (Table 3) indicates that for the soils under study the correlation is very good. The percolation data correlate in a general way also with the plasticity indices. The two measurements together, as indicated in this study, would appear to give a very good idea of what may be expected in field practice.

The percolation rates are given for the natural soil slaked without previous puddling and for 100-gram mud balls dried and then slaked in water. In the latter case the soil was prepared by wetting to about the field capacity and pressing and rolling into balls. After thorough drying the balls were placed in 4-inch Buchner funnels which were

immersed in water to allow the soil to slake in the funnel, where it was later percolated.

The percolation rates (Table 3) indicate that when the more refractory soils are puddled and made into balls they do not recover their structure entirely by once drying and slaking. This indicates their sensitivity to working when too wet. The Meyer, Coker, and Medford soils are so easily injured by working when too wet that the greatest care must be used in their management.

TABLE 3.—*Plasticity and permeability to water of the soils under study.*

Soil type and horizon	Plasticity number	Percolation, minutes*		Field behavior
		Field soil	100-gram ball	
Aiken clay, A	0.9	12.3	14.2	Well drained, pulverulent, friable
Aiken clay (forest), A	6.0	20.8	16.7	Well drained, pulverulent, friable
Medford gravelly clay loam, A	9.8	33.5	91.0	Fair drainage, slightly friable, and pulverulent
Dayton silty clay loam, A	4.5	33.0	29.7	Slightly plastic, quite permeable, and friable
Dayton silty clay loam, B	16.2	101.8	169.3	Very plastic, no granulation, impermeable to water
Cove clay subsoil, B	16.0	31.5	60.8	Very plastic, compact, heavy, poor drainage
Meyer clay adobe, A	15.9	122.8	254.5	Plastic, run together, no granulation, impermeable
Coker clay adobe, A	29.8	31.7	40.6	Very plastic, no granulation, slight drainage

*The percolation rates represent time in minutes for 400 cc of water to percolate through the soil by the method of Bouyoucos (8).

SIGNIFICANCE OF SOIL STRUCTURE

Heavy soils are not infrequently abundantly supplied with mineral nutrients. Cove clay of this study is a rich soil measured in terms of its stock of nutrients. Likewise, the Meyer, Coker, and Medford soils are highly productive when properly handled, but because of their refractory physical properties, tillage operations are sometimes almost impossible. The expense and difficulty of tillage, drainage, or irrigation,

therefore, cause these soils to be classed as undesirable from the standpoint of practical agriculture. But because other soils are not available in the territory where they occur, such soils are sometimes highly developed and become very valuable. This is true in the pear-growing sections of the Medford area.

Desirable biological processes in the soil are much dependent upon soil structure and a supply of readily available humus is essential to biological activity. Heavy, water-logged, and impenetrable soils, under natural conditions contain only a shallow layer of humus in the surface soil. There is little in the deep soil therefore to support biological action. Due to this condition the crop must be produced largely from the supply of nutrients in the surface soil. Under natural conditions only about 16 inches of the Dayton soil is actively supporting plant growth.

It is quite apparent that any laboratory data here presented fall short of evaluating all the factors responsible for soil structure. A specific example is found in the Meyer and the Coker soils. If compared on the basis of the plasticity indices they appear to be quite unlike. Both are refractory soils, perhaps the Meyer more so than the Coker, yet the plasticity indices indicate the reverse The percolation data, on the other hand, reverse the relationship as compared with the plasticity indices and greatly exaggerate the difference in the two soils.

Discrepancies of this nature are abundant Yet all the more refractory soils can be easily separated from the Aiken which has very desirable physical properties. Likewise, the very refractory subsoil horizon on the Dayton series can be easily distinguished from the more friable surface.

It is quite apparent, therefore, that there are properties inherent to the soil which have a great influence over its physical behavior and which are elusive of evaluation by any single method here applied. Bennett (5) accounts for some of these differences upon the basis of chemical composition as expressed in the ratio $SiO_2 \div R_2O_3$. But this ratio by no means accounts for the whole difference, as many soils exhibit a very desirable physical behavior, even though falling in the group of plastic soils.

FACTORS AFFECTING SOIL STRUCTURE

In mechanical analyses all particles below 1 micron average diameter are classed as colloidal, although the water vapor absorption method does not make a distinct division on this basis. When the entire clay fraction is considered the largest particles are 5 microns

in diameter. The silt then covers everything from 5 to 50 microns. In this work silt was obtained by difference and includes everything between the sand and the colloidal fraction. The fine fractions make up from 60 to 80% of the soil materials used in this study. Though fine material is necessary to produce a poor structure, there is no correlation between the field behavior of these soils and their mechanical analyses, or their colloid content.

TABLE 4.—*Mechanical analyses and slaking characteristics of the soils under study.*

Soil type and horizon	Total sand %	Silt* %	Colloidal clay† %	Slaking characteristics
Aiken clay, A	17.8	23.3	58.9	Ball cracked into several large pieces, slaked very little and that into flaky, granular particles of definite structure
Medford gravelly clay loam, B	35.5	26.8	37.7	Slaked rapidly into a mass of granular and flaky particles, slight tendency to be powdery
Dayton silty clay loam, A	32 4	35.5	32.1	Slaked into a flaky and platy structure at a moderate rate
Dayton silty clay loam, B	21.1	34.6	44.3	Slaked from outside of ball into a powdery mass having no visible structure within one-half hour
Cove clay subsoil, B	21.4	25.6	53 0	Slaked into a powdery, soggy mass, having little visible structure within 1½ hours
Meyer clay adobe, A	36.4	25.5	38 1	Slaked into a very fine nearly powdery mass with very little structure
Coker clay adobe, A	18.7	5 6	65.7	Slaked quite rapidly into a mass of medium size particles having a fair structure

*By difference. †By water adsorption method (17).

There is a very noticeable difference in the way in which soils with good and poor structure slake when the dry soil is wet (Table 4). The refractory soils slake into a heavy, compact, soggy mass. The particles are very small in size, and there appears to be no pore space left. Slaking occurs always from the surface and gradually inward when the soil is made into balls, as though the water were unable to penetrate any but the surface of the ball of soil. The friable soils, on the other hand, slake into larger aggregates, irregular in shape, but granular and loosely arranged. The whole ball cracks apart more or less at once, and there are few of the smaller aggregates and little tendency to pack together into a formless mass.

The slaking structures seem to be characteristic of the soils, as the same soil slaked repeatedly always follows the same type of slaking. The original dried soil also slakes in much the same manner as the dried balls prepared according to the procedure of Bouyoucos (8).

Correlation of the slaking behavior indicates that the refractory structures are due to inability of the soil to assume the form of large aggregates, and lack of resistance to forces which break up the structure. The fine soil particles break away easily and by infiltration plug such pore space as occurs. The ameliorable soils are more sponge-like in structure and coarsely granular at all times. The fine particles do not separate in slaking and do not plug the larger pore spaces. In fact, so difficult is it to disperse the Aiken soil that it is practically impossible to remove silt and clay from the sand separates. There is, therefore, both more pore space and larger pores in the friable soil with practically no tendency for plugging the pores by infiltration of colloidal matter.

The same condition is shown in the shrinkage coefficients. The refractory soils undergo greater volume changes when the wet soil is dried. Such pore space as is filled with water in the moist soil tends to collapse upon drying, giving a higher shrinkage coefficient. The friable soils hold more easily available water as shown by the moisture content at the lower plastic limit (Tables 2 and 7), indicating more pore space than in the refractory soils. Yet the friable soils upon drying shrink less, or show less tendency to collapse upon loss of water. The dried soil is then left with an open pulverulent structure that is easily broken up to a good tilth, instead of the compact stone-like structure found in the refractory soils.

Bennett and Allison (6) report highest pore space in the most friable, pervious structured soils. In one very pervious soil they report 80% pore space in spite of the fact that the soil is high in colloidal matter. The pore space in the more refractory soils was only about 43%. The plasticity index in Bennet and Allison's (6) soils, as in our soils, was much lower for good than for refractory soils.

Any data available at the present time make possible little more than a simple observation of facts. There are apparently some deep-seated soil characters which are responsible for the structure that the soil will assume. In some soils a relatively small fraction of fine material may apparently cause a very refractory soil. In other cases the soil may be mostly fine material and yet possess a very desirable structure.

Bureau of Soils workers (1, 16) have found the type of weathering occurring in the soil a very important factor affecting its characteris-

tics. Lateritic weathering results in a low $SiO_2 \div R_2O_3$ ratio, and low values in general for soil properties, such as shrinkage, plasticity, heat of wetting, and exchangeable bases. The lateritic soils do not erode readily and are characterized by a porous and permeable structure. Such soils are also deep and uniform in character to great depth. These humid-tropical soils have a dominant tendency to weather to the simple oxides of silica, iron, and alumina, with the loss of the greater portion of soluble bases. These simple components behave more or less like inert matter.

The humid-temperate soils, on the other hand, do not weather to the simple end products, but are made up of more of the complex alumino-silicate or clay end products. These soils have a higher $SiO_2 \div R_2O_3$ ratio, often a higher acidity, more replaceable bases, are more plastic, and are often more impervious and difficult of culture.

Certain well-known factors modify the structure and character of all soils. Soil reaction is sometimes an important factor, but principally when extremes are developed. A very alkaline soil (black alkali) usually has a badly dispersed structure and is impermeable and refractory to handle. Acid soils are perhaps somewhat dispersed, but are not notoriously difficult because of poor structure. Perhaps soils which are well supplied with lime and are near neutrality have a more favorable structure. However, the Cove, Meyer, Coker, and Medford soils of this series are abundantly supplied with lime and are neutral or somewhat alkaline, and yet all are refractory soils.

From the standpoint of crop production a high base exchange capacity is a favorable factor. A high percentage of exchangeable calcium among the bases is usually considered favorable to the physical condition of the soil, as well as to its productivity. Whether a soil will show the most tendency to flocculate with simply sufficient calcium to replace the hydrogen in the complex is doubtful. It seems more probable that an excess in the form of a soluble calcium salt, such as gypsum, would result in the best flocculated and most pervious structure (4).

Two of the most refractory soils were selected for treatment to determine whether the soil structure could be improved. Burned lime was used at rates of 1, 2, 4, 8, and 16 tons per 2,000,000 pounds of soil. The soils were also percolated with calcium chloride to produce a calcium-saturated complex. The other treatment consisted in replacing all the bases with hydrogen by leaching with 0.05 N hydrochloric acid.

The data presented here indicate that all the various treatments

improved the permeability of the soils to water. Simply slaking the soil in saturated gypsum solution and then percolating with pure water caused a marked increase in permeability with two of the most refractory soils. The effect of gypsum may be simply the flocculating action of an electrolyte.

It would seem that any treatment which would change the manner of slaking might prove very helpful in improving the soil structure. Any treatment which would cause the soil to break up into a coarsely granular mass and prevent the minute particles from breaking away and filling up the soil pores should be very effective. This is the type of slaking which the good-structured soils undergo.

The calcium chloride treatment was especially effective in producing a granular crumb structure, even in the Dayton soil series which previous to treatment broke down with no discernible structure. The improved structure appeared to be more or less permanent as several hours leaching resulted in little change in permeability as indicated by the percolation rate. Calcium chloride was used for the purpose of saturating the absorption complex with calcium by replacing all other exchangeable cations. The excess of calcium chloride was then carefully washed out of the soil before any percolation measurements were made. It would appear, therefore, that the improved structure was not alone due to the simple flocculating action of an electrolyte but that the change was more deep-seated and intrinsic within the soil

In these comparisons the effect of quick-lime, comparing rates from 1 to 16 tons per acre, is especially interesting Although the heavy rates of treatment produced greatest improvement in structure, even the lightest treatment made a very marked improvement in the permeability The lime seemed equally effective in flocculating the alkaline or the acid soil.

It is interesting that the treatment of the soils with 0.05 N hydrochloric acid to remove the replaceable bases in exchange for hydrogen produced just as marked improvement in permeability of the soils to water as any treatment. Perhaps treating with acid tends to produce lateritic characteristics of all the soils Burgess (11) and Mattson (15) report that there is a "build up" and "break down" of the exchange complex which occurs naturally or may be brought about rather readily. An acid condition is reported to have resulted in "break down" of the base exchange capacity (11). Presumably this "break down" is a step in the direction of laterization.

A study of the data (Table 5) shows the comparative effects of the different treatments on two of the most refractory soils. It is possible

TABLE 5.—*Time in minutes for 400 cc of water to percolate through 100 grams of soil under a pressure of 65 to 67 cm.**

Soil type and horizon	100 grams of soil treated with lime						Gypsum-slaked soil	Ca-saturated soil	H-saturated soil
	Soil untreated	1 ton CaO	2 tons CaO	4 tons CaO	8 tons CaO	16 tons CaO			
Dayton silty clay loam, B......	169	85	75	34	23	15	32	22	17
Meyer clay adobe, A ...	254	65	48	29	18	16	38	11	13
Aiken forest, A ..	8	—	—	--	.	...	--	12	—

*The lime-treated soils were mixed with CaO at the rates shown, made into mud balls, dried, slaked in water, and percolated. The gypsum-slaked soil was percolated with pure water, as above Calcium saturation was accomplished by treating the soil with N/1 $CaCl_2$, leaching, and washing free of $CaCl_2$. The H-saturated soil was prepared by leaching with 0.05 N HCl, and washing free of excess acid.

that the effect of these treatments, if made in the field, would gradually disappear. The solubility of lime is so low, however, and the percolation rate so slow that it is difficult to demonstrate a disappearance of the effect in the laboratory

TABLE 6 *Milliequivalents of exchangeable bases per 100 grams of soil.*

Soil type and horizon	Electrometric pH	H	Ca	Total bases	Calculated exchange capacity	Colloid %
Dayton silty clay loam, A	5.8	3.6	14.4	15.5	19.1	32.1
Dayton silty clay loam, B	5.8	3.6	19.6	22.5	26.1	44.3
Aiken, forest, A	6.3	6.4	24.0	25.5	31.9	88.3
Aiken, A	5.6	8.4	7.1	7.5	15.9	58.8
Cove clay, B ..	7.9	2.4	37.5	43.3	45.7	53.0
Meyer clay adobe, A	8.0	0.0	26.5	27.5	27.5	38.1
Coker clay adobe, A	7.0	2.8	36.5	40.0	42.8	65.7
Medford gravelly clay loam, B	7.0	2.0	20.2	23.0	25.0	37.7

A study of the data (Table 6) shows that the good-structured soils have a low exchange capacity in proportion to colloid content, while the more refractory soils show a high exchange capacity, indicating a large percentage of reactive colloidal matter. The low exchange capacity of the friable soils of the Aiken series indicates that these soils have already experienced a "break down" of the complex. While they show high total colloidal matter, there is only one-half to one-sixth as much of the colloid in an active form capable of participating in exchange reactions. The data indicate that most of the soils have a very good supply of bases. Calcium is evidently the principal base. The Aiken surface is the only soil of a specially low degree of saturation, and it is about 50% saturated.

None of these soils are high in organic matter and no organic treatments were made for comparison. It is known, however, that organic matter has a very favorable effect upon soil structures and the physical properties of the soil in general. Baver (2, 3) has reported some recent work on the effect of organic matter on the physical properties of soils. This is a phase of the problem that should receive more study. In field practice, lime, gypsum, and organic matter in the form of farm and green manures are available for use in improving refractory soils.

RELATION OF SOIL MOISTURE AND SOIL STRUCTURE

A flocculated soil is not always intrinsically or structurally improved. A structural particle and a floccule are not necessarily identical. Thus, iron and aluminum are precipitated with amonia and by digesting a short time become flocculated. When placed on the filter, however, the flocculated mass proves to be a dense gel, practically impermeable to water.

Highly colloidal soils of poor structure behave in much the same way. Water fails to penetrate, and all moisture movement is extremely slow. Highly colloidal soils of good structure, on the other hand, are readily permeable to water, are well aerated, and are very amenable to tillage.

To modify soil structure in field practice is very desirable from the standpoint of soil moisture relationships. The heavy refractory soils have a high moisture capacity, but the moisture is not easily usable by the plant unless soil structure is favorable to aeration and root penetration. Not only drainage, but the availability of soil moisture therefore depends almost directly upon soil structure.

Plants obtain moisture and nutrients through the root hairs which are in contact with the moist soil surface. Thomas (20) estimates from vapor pressure measurements that the water film of the soil interface is about 20 millimicrons thick at the hygroscopic point. Soils at field capacity retain roughly three times the amount of water present at the hygroscopic point. The film thickness would then be increased whether in a proportionate degree or not. The film would no doubt vary in thickness from 50 millimicrons to perhaps 0.1 of a micron, or the water would concentrate in the smaller capillaries and in the soil spaces as wedge water of unknown thickness and extent.

Since colloidal particles are mostly 0.1 micron and smaller in diameter, and if the water is considered as film water, the film thickness would equal the diameter of the colloid particle, unless the colloids assume a structural aggregation into larger groups. Practically, it is

impossible to have 0.1 micron films on individual colloidal particles, as the soil would be water-logged, the condition which tends to prevail in such soils as Dayton and Cove.

TABLE 7.—*Correlation of hygroscopic coefficient and lower plastic number.*

Soil type and horizon	Hygroscopic coefficient		Lower plastic number for soil %	Difference of hygroscopic and lower plastic number for soil	Moisture equivalent Hg. C. x 2.7 for soil %
	Of soil %	Of separated colloid %			
Dayton, A ..	6.86	22.2	25.0	18.14	18.52
Dayton, B.. ..	11.75	26.5	21.8	10.05	31.72
Aiken, forest, A	14.23	16.2	40.2	25.97	38.42
Aiken, A . .	10.58	17.0	32.9	22.32	28.57
Aiken, B ...	11.48	19.8	30.0	18.52	31.00
Aiken, C .	12.60	18.5	28.7	16.10	34.02
Cove, B .	15.15	28.6	20.0	4.85	40.91
Meyer, A .	10.67	28.0	18.0	7.33	28.78
Coker, A	19.53	29.7	19 14	0.39	52.53
Medford, B	—	— -	16.18	——	——

Structural units of much larger size, perhaps of the average diameter of very fine sand which is 50 to 100 microns, make it possible to have in the soil at one and the same time an adequate thickness of moisture film and wedge water for free movement into the plant and good aeration to make root development possible. This relationship is brought out especially by the data (Table 7) which show the difference between the hygroscopic coefficient and the moisture at the lower plastic limit. The Dayton subsoil and the Cove, Meyer, and Coker soils show a much smaller difference than is found in the Aiken soil which has a good structure. It is noticeable also that the Aiken forest A and the other Aiken A and B show a lower plastic limit which is very near the moisture equivalent calculated from the hygroscopic coefficient. The very refractory Dayton B and the Cove and the Coker, on the other hand, show a moisture equivalent much above the lower plastic limit.

It may be observed that when the lower plastic limit is more than twice (three times for the best soils) the hygroscopic coefficient, a good soil structure is found. When the lower plastic limit is less than twice the hygroscopic coefficient, on the other hand, a poor structure is found.

These observations explain a very prominent characteristic common to the soils of the Aiken and similar series which appear to be lateritic in character. The soils absorb rainfall so readily that they may be tilled almost at once after a rain. Even though there is a high

moisture capacity, the soil is never highly plastic or puddled. The very porous structure allows the gravity water to disappear very quickly. The soil is then in a workable state, as there is a very narrow plastic range and the lower plastic limit is high. Little risk of endangering soil structure follows, therefore, from tillage almost immediately after rains. Bennett and Allison (6) make a similar observation in regard to the lateritic soils of Cuba.

These variations in moisture relationships result undoubtedly from fundamental differences in soil structure. These fundamental differences explain the water-logged condition of Dayton B when it is moist and the great difficulty in securing water penetration in irrigating Meyer and Coker soils, and also the difficulty of drainage of all the refractory soils. Even the distinction between the surface of the Dayton soil and the more refractory subsoil is brought out in this relationship.

The same relationship is nicely indicated by a study of the hygroscopic coefficient of the separated colloidal matter (Table 7). Here again the hygroscopic coefficient distinguishes the refractory subsoil from the better surface soil of the Dayton series and likewise distinguishes the more friable Aiken soils from the refractory soils. The refractory soils consistently show a higher hygroscopic coefficient for the separated colloids.

GENERAL DISCUSSION

A consideration of the data here presented would indicate the dominating influence of soil structure in all soil moisture relationships. Likewise, the data indicate that structure is something inherent in the soil, slowly developed perhaps under age-long influences that determine the general physical character of the soil and its value for crop production.

While soil structure is much modified by the farmer and is therefore somewhat under his control, nature has already set limits within the soil beyond which he cannot improve in any practical way. Yet no doubt refractory soils always will be kept under cultivation, and it is very important to know to what extent and by what means soil structure may be most favorably and economically modified. For this significant reason more work on this problem seems justified. Further studies should include the effect of organic matter and of green manure crops which develop an extensive root system to penetrate and open the soil. It seems probable, therefore, that a study of treatments under field conditions should give considerable practical help in the solution of problems of soil structure and management.

CONCLUSIONS

This study was made as a preliminary investigation to determine whether certain procedures might be of use in making studies of soil structure.

The Bouyoucos method of measuring soil permeability to water seems satisfactory as a percolation method. The method is sufficiently sensitive to distinguish soil types that show marked differences in behavior in the field, and to distinguish between surface and subsoils when these are appreciably different The method also distinguishes the effects of treatments and different rates of treatment rather consistently. The results likewise correspond with the field behavior of the soils.

The plasticity indices appear to indicate significant structural differences. The more desirable soil structures are associated with a low plastic range and the refractory soils with a high plastic range.

There is little or no correlation between soil structure and the amount of of colloidal material.

Chemical treatments may prove helpful to improve soil structure in the field, but the feasibility of such improvement can be determined only by field trial.

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THE RELATIONS AMONG FERTILIZER TREATMENT, SOIL MOISTURE, ORGANIC MATTER, AND YIELD OF VEGETABLE CROPS[1]

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The investigations described in this paper were undertaken to ascertain the extent to which fertilizers may influence the moisture content of soils under certain field conditions. Measurements were made on the amounts of organic matter and moisture in certain plats of a fertilizer experiment, and a study was conducted on the relations among fertilizer treatments, organic content, soil moisture, and crop yields. At the time the work was begun, in 1928, the plats on which measurements were taken had been under treatment continously for 12 years as part of an experimental study on the fertilizer require-

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ments of cabbage, potatoes, tomatoes, and wheat followed by mixed grass and clover, the latter constituting a cover crop. These crops had been grown in a 4-year rotation in the order named. In 1928, sweet corn was substituted for the wheat and mixed cover crop, so that four truck crops were grown in succession.

The soil of the experiment is Hagerstown clay loam, which, before the experiment was begun, had been occupied by general farm crops, and was medium in productiveness. This soil is of the same series as that of the Jordan soil fertility plats of the Pennsylvania Agricultural Experiment Station on which similar studies were made by Brown, *et al.* (2, 3, 4).[3] On the vegetable fertilizer plats on which the present studies were made, however, the manurial treatments were more frequent and much heavier than on the Jordan plats.

The treatments given the different plats under study are shown in Table 1. These treatments were applied in alternate years during the first 4 years of the experiment. During the next 4 years, the fertilizers were applied to all crops except the wheat and green manure crop; and during the last 4 years, fertilizers were applied yearly. All plats except those receiving 10 tons of manure and complete fertilizer were planted annually with a cover crop of rye and vetch which was seeded as soon as the truck crop had been harvested.

The plats were considered as of four series, *viz.*, the nitrogen, the phosphorus, the potassium, and the manure series. In the separate series, the effect of a given element was studied in connection with certain plats, all of which received like amounts of two plant food elements, while the amounts of the third element, the one under study, were different on the different plats of the series. Thus the effects of nitrogen were studied in connection with certain plats, each of which received 100 pounds of phosphoric acid (P_2O_5) and 80 pounds of potash (K_2O) to the acre, but on which the rate of application of nitrogen (N) ranged from 0 to 90 pounds to the acre, with increments of 30 pounds. The phosphorus plats each received 60 pounds of nitrogen and 80 pounds of potash to the acre, with the application of phosphoric acid ranging from 0 to 150 pounds to the acre, with increments of 50 pounds. The standard applications on the potash plats were at the rate of 60 pounds of nitrogen and 100 pounds of phosphoric acid to the acre, with the applications of potash ranging from 0 to 120 pounds to the acre, with increments of 40 pounds. The carriers were nitrate of soda, superphosphate (16 %), and muriate of potash.

The effects of stable manure were studied in connection with certain

[3]Reference by number is to "Literature Cited," p. 202.

plats which received manure at the rate of 10 tons, together with 60 pounds of nitrogen, 100 pounds of phosphoric acid, and 80 pounds of potash, or the equivalent of 1,000 pounds of 6–10–8 commercial fertilizer to the acre; and others receiving 20, 30, or 40 tons of manure each, without commercial fertilizer. For purposes of comparison, certain plats receiving 1,000 pounds of 6-10-8 fertilizer to the acre, but with a cover crop of rye and vetch instead of 10 tons of manure, were included in this section of the study.

TABLE 1.— *Fertilizer treatments of the plats included in the study.*

Plat No.	Fertilizer treatment, lbs. per acre			Manure, tons per acre
	N	P_2O_5	K_2O	
		Nitrogen Series		
1–8, 4–10	0	100	80	—
2–2, 5 16	30	100	80	
2–3, 5–15	60	100	80	—
2–4, 5–14	90	100	80	—
		Phosphorus Series		
1–7, 4–11	60	0	80	—
2–6, 5–12	60	50	80	
2–7, 5–11	60	100	80	—
2–8, 5–10	60	150	80	—
		Potash Series		
1–6, 4–12	60	100	0	—
2–10, 5–8	60	100	40	
2–11, 5–7	60	100	80	—
2–12, 5–6	60	100	120	
		Manure Series		
6–7, 6–15	60	100	80	0
6–3, 6–11	60	100	80	10
1–14, 4–4	—	—	—	20
1–15, 4–3	—	—	—	30
1–16 4–2	—	—		40

It was planned to measure the moisture content of the surface soil in these plats at weekly intervals through a considerable portion of two growing seasons. This plan was followed between the dates which are stated later, in so far as the weather permitted. The samples of soils which were dried in making these measurements in 1928 were kept in tightly closed containers for later measurements of the percentages of organic matter.

The crop yields which were considered in the studies were the total yields of the different crops in the separate seasons. Special attention was paid to the yields of sweet corn in 1928 and of cabbage in 1929, since these crops occupied the plats at the time the measurements of moisture were made.

METHODS

ESTIMATING PERCENTAGE OF MOISTURE

In estimating the moisture content of the plats, composite samples made of six borings were taken from each plat. The borings were made at approximately the same place each time the plats were sampled. Four of the borings were located one at each corner of the plat at a point 4 feet from the ends and sides. The other two were located at points midway between the ends and 4 feet from the sidse.

The borings were made by driving a section of iron pipe 3 inches in diameter and 12 inches long into the soil to a depth of 7 inches. The cylinders of soil thus removed were collected in a pail and thoroughly mixed. Sufficient soil to provide two samples of about 50 grams each was sifted through a sieve with round holes 4 mm in diameter. The samples were placed at once in small metal boxes provided with tightly fitting covers The samples collected in 1928, after being dried, were stored in tightly covered metal containers for later use in measuring the organic matter in the soil. Whenever samples were taken, the plats were sampled in the same order. In 1928 from 6 to 9 hours were required for taking the samples; in 1929 less than 4 hours were required

When this work was started in 1928, it was planned to measure the soil moisture content weekly. Frequent rains prevented close adherence to this schedule in 1928. In 1929, with but one exception, weekly measurements were made between June 5 and August 13.

MEASURING PERCENTAGE OF ORGANIC MATTER

The soil used for measurements of the organic matter content of the plats was that collected in 1928. The organic content was estimated in terms of the percentage of organic carbon present in the soils. The latter was calculated as the difference between the total percentage of carbon and the percentage of inorganic carbon in the soils. The percentage of organic matter was calculated by multiplying the percentage of organic carbon by the Wolff factor (1.724). The percentages of both total and inorganic carbon were measured in triplicate, using wet combustion methods. Total carbon was estimated by the chromic acid method as modified by White and Holben (11), while inorganic carbon was measured by the wet combustion method suggested by Gortner (5).

TABLE 2.—*Yields of crops on the plats receiving different fertilizer treatments in terms of percentages of standard yields for the respective seasons.**

Treatment per acre	Plat No.	Potatoes 1922	Potatoes 1926	Potatoes Average	Tomatoes 1919	Tomatoes 1923	Tomatoes 1927	Tomatoes Average	Cabbage 1917	Cabbage 1921	Cabbage 1925	Cabbage 1929	Cabbage Average	Sweet corn, 1928	All crops
							Nitrogen								
0	1–8	111.3	91.2	101.3	82.0	133.3	74.3	96.5	70.4	103.8	82.9	71.7	82.2	90.6	91.2
	4–10	126.6	106.7	116.7	97.3	102.5	101.0	100.3	90.3	103.8	98.9	69.7	90.8	71.0	96.7
30 lbs.	2–2	115.2	102.4	108.8	98.0	136.0	100.2	111.4	83.0	103.5	100.4	95.0	95.5	73.0	100.6
	5–16	71.9	115.1	93.5	81.4	53.1	83.7	72.7	79.9	50.2	79.4	80.8	72.6	23.4	69.9
60 lbs.	2–3	118.6	95.5	107.1	82.3	137.0	97.5	105.6	99.5	117.6	102.0	111.8	107.7	118.8	108.1
	5–15	71.5	88.0	79.8	79.2	58.9	90.8	76.3	100.5	69.7	89.3	94.4	88.5	52.5	79.5
90 lbs.	2–4	127.4	88.6	108.0	97.2	143.2	117.5	119.3	118.5	121.9	147.8	118.3	126.6	110.5	119.5
	5–14	68.3	85.3	76.8	82.4	49.0	83.7	71.7	88.5	61.6	83.0	82.4	78.9	107.5	79.2
							Phosphorus								
0	1–7	81.6	45.3	63.5	55.7	67.8	84.6	69.4	66.8	43.1	55.0	51.0	56.5	133.8	69.5
	4–11	63.2	44.8	54.0	65.4	38.0	44.0	49.1	54.7	19.4	24.8	15.8	28.7	110.0	48.0
50 lbs.	2–6	136.6	63.1	99.9	106.6	174.1	93.6	124.8	92.9	127.0	109.6	107.0	109.1	139.2	114.0
	5–12	72.1	78.0	75.1	63.1	40.2	72.0	58.4	72.8	44.4	81.4	83.7	70.6	82.0	66.9
100 lbs.	2–7	159.0	95.0	127.0	140.1	153.5	122.0	138.5	116.0	160.3	102.0	133.4	127.9	133.7	131.4
	5–11	85.1	103.7	94.4	74.6	60.1	95.8	76.8	104.0	69.7	88.1	84.0	86.5	113.5	87.9
150 lbs.	2–8	162.1	109.3	135.7	146.8	156.7	165.5	156.0	110.0	168.8	96.5	117.7	123.3	153.0	138.5
	5–10	100.1	116.0	108.1	109.1	99.5	130.6	113.1	113.3	107.7	106.3	83.6	102.7	118.2	107.5

							Potassium								
0	1–6	128.2	63.4	95.8	90.5	130.9	75.9	99.1	109.0	182.0	103.6	118.6	128.3	153.2	115.4
	4–12	102.8	75.4	89.1	100.8	103.1	109.1	104.3	92.5	119.6	100.1	101.8	103.5	137.0	104.2
40 lbs.	2–10	113.2	91.1	102.2	103.1	132.0	100.5	111.9	102.2	114.7	106.5	99.6	98.0	135.8	106.7
	5–8	85.1	103.0	94.1	95.9	90.4	98.3	94.9	105.0	102.2	95.6	87.9	97.9	74.8	92.9
80 lbs.	2–11	154.8	106.3	130.6	88.3	117.1	93.4	99.6	103.9	102.2	157.0	89.7	113.2	123.0	113.6
	5–7	83.2	105.8	94.5	87.5	78.1	103.9	89.8	110.0	102.8	86.0	95.8	98.7	82.0	93.5
120 lbs.	2–12	139.2	121.0	130.1	91.0	105.0	84.3	93.4	94.3	102.7	107.7	90.0	98.7	122.5	105.8
	5–6	61.1	111.0	86.1	82.6	67.6	127.8	92.7	98.0	87.2	99.5	122.7	101.9	56.8	91.5
							Manure								
6–10–8, rye and vetch	6–7	64.3	114.0	89.2	93.4	99.0	102.1	98.1	98.0	92.1	100.0	89.5	94.9	44.5	89.7
	6–15	63.4	72.9	68.2	84.0	36.5	55.9	58.8	81.2	.45.0	106.5	64.2	74.2	57.7	66.7
6–10–8, 10 tons	6–3	142.0	158.2	150.1	123.1	204.0	156.2	161.1	94.6	102.0	115.6	86.4	99.7	199.0	138.1
	6–11	146.5	157.8	152.2	118.0	145.8	181.2	148.3	94.1	97.5	108.8	81.5	95.5	162.0	129.3
20 tons	1–14	182.6	175.0	178.8	162.5	206.0	201.5	190.0	72.5	135.3	112.3	55.7	93.9	186.0	138.9
	4–4	194.5	134.1	164.3	196.6	171.8	190.0	185.9	88.2	126.9	113.6	127.3	114.0	162.0	150.4
30 tons	1–15	207.7	212.0	209.9	209.3	196.5	229.0	208.6	77.6	161.9	117.7	84.2	110.4	240.0	172.7
	4–3	215.0	180.0	197.5	224.0	212.0	219.5	218.5	86.9	154.1	106.0	135.8	120.7	202.0	173.6
40 tons	1–16	186.8	173.9	180.4	210.0	187.8	212.5	203.4	62.4	104.3	132.1	91.4	97.6	232.0	159.3
	4–2	224.0	193.2	208.6	258.3	226.0	204.0	229.4	98.5	159.6	108.0	144.3	127.6	207.0	182.3

*The standard yield for a given crop in a particular season was the average yield of the crop for that season on 17 plats each receiving 60 pounds of nitrogen, 100 pounds P_2O_5, and 80 pounds K_2O to the acre.

PRESENTATION OF DATA

CROP YIELDS

The experiment of which the plats studied are a part consists of four equal sections of 102 plats each. The fertilizer treatments on similarly located plats are the same for all sections, and are applied annually. The crops, including cabbage, early potatoes, tomatoes, and sweet corn, are rotated in the order named on each section, and also from section to section, so that each crop is grown on a given section once in every 4 years and every crop is grown annually on one of the four sections. In 1928, the plats under study were occupied by sweet corn and in 1929 by midseason cabbage.

The yield records of the entire experiment to the end of 1926 have been presented and discussed by Mack (8). For the purposes of this discussion, it is sufficient to report the yields of only those plats on which measurements of moisture were made. The general relations between the fertilizer applications and crop yields in the experiment as a whole, however, will be considered briefly, in order to throw as much light as possible on the subject under study.

Table 2 presents the yield records of the different crops on the plats investigated in terms of percentages of standard yields for the respective seasons. These standard yields were the average yields of the given crop in the particular seasons on 17 different plats, all of which received the same fertilizer treatment, *viz.*, 60 pounds of nitrogen, 100 pounds of phosphoric acid (P_2O_5), and 80 pounds of potash (K_2O) to the acre from nitrate of soda, 16% superphosphate, and muriate of potash, respectively. This method of reporting the yields was adopted because it made the results from different seasons and different crops more nearly comparable to each other.

The yields of plats which constitute ascending series for the different fertilizer elements are grouped in the separate sections of the table, and the duplicate plats under the same treatment are placed together. The amounts of the particular elements as listed were applied with standard amounts of the other two elements, the standard amounts being 60 pounds of nitrogen, 100 pounds of phosphoric acid, and 80 pounds of potash,

It is apparent that the yields on duplicate plats under the same treatment are frequently quite different. Plat 1-7, for example, consistently yielded more that did 4-11, which received the same fertilizer; plats 2-4 and 2-6 yielded considerably more than 5-14 and 5-12, respectively, which received like fertilizer treatments. Only small differences were present among average yields for the different treatments in either the nitrogen or the potash series, and these were

probably not significant. In the phosphorus series, however, the differences among the average yields for the various treatments were fairly large. Although the duplicate plats receiving like treatments had widely different yields, the fact that the increases in yield for phosphorus were consistent in both series of plats lends some significance to the differences. The averages for all crops on plats receiving barnyard manure show marked increases for larger amounts of manure up to 30 tons to the acre. The largest amount applied, 40 tons to the acre, gave no larger returns on the average than 30 tons. With cabbage, however, the gains for barnyard manure were not consistent.

In the report already cited (8), the relations pointed out for the experiment as a whole are not altogether in agreement with those just suggesgted. With respect to phosphorus and barnyard manure, the results for the plats listed in the table are substantially in agreement with those for the entire experiment. In the experiment as a whole, however, the differences are significant. With respect to nitrogen and potash, certain significant differences were shown to be present in the whole experiment which are not apparent in the plats. For example, nitrogen produced gains in yield of cabbage which were greater for larger amounts of nitrogen up to 60 pounds to the acre. With the other crops, however, no increases in total yield were evident for nitrogen applications. The smallest amount of potash, 40 pounds to the acre, produced larger yields of all crops than did larger amounts or none at all.

The fact that the differences for the experiment as a whole are not evident in the yields of the plats under discussion suggests that the effects of the fertilizer treatments on these plats were masked by the effects of other conditions prevailing on these plats. One of these conditions has been pointed out by Pelton (9) as differences in the lime requirement of the plats. Other conditions will be suggested later in this paper.

SOIL MOISTURE

The data on soil moisture consist of the percentages of moisture in soil samples collected as previously described on the various dates specified in Table 3. The percentages given are averages of duplicate measurements which in most cases agreed closely. As in the case of the crop yields, the data on moisture are grouped so as to show the effects of increasing amounts of a particular fertilizer element or substance, and duplicate plats with the same fertilizer treatment are placed together.

The average percentages in 1928 were considerably higher than

TABLE 3.—*Percentage of moisture on plats*

		1928					
Treatment per acre	Plat No.	July 25	Aug. 14	Aug. 21	Aug. 28	Sept. 5	Average
		Nitrogen					
0	1–8	25.90	21.46	16.22	20.81	19.61	20.80
	4–10	22.75	18.96	14.57	18.60	17.17	18.41
	Av.	24.32	20.21	15.39	19.70	18.39	19.60
30 lbs.	2–2	25.31	22.63	16.72	20.96	19.45	21.01
	6–16	25.27	22.39	17.80	21.41	20.03	21.38
	Av.	25.29	22.51	17.26	21.18	19.74	21.20
60 lbs.	2–3	25.60	21.43	16.95	20.59	18.52	20.62
	5–15	23.66	21.22	17.09	20.95	19.82	20.05
	Av.	24.63	21.32	17.02	20.77	19.17	20.33
90 lbs.	2–4	25.48	21.64	16.44	20.18	19.62	20.67
	5–14	24.37	21.71	17.80	20.92	19.64	20.56
	Av.	24.92	21.67	17.12	20.55	19.63	20.62
		Phosphorus					
0	1–7	25.19	20.94	15.48	20.08	19.27	20.19
	4–11	22.34	17.88	13.18	18.17	16.15	17.54
	Av.	23.76	19.41	14.33	19.12	17.71	18.87
50 lbs.	2–6	25.81	21.98	16.58	20.91	19.76	20.90
	5–12	25.56	24.02	19.26	22.85	22.18	22.77
	Av.	25.68	23.00	17.92	21.88	20.97	21.83
100 lbs.	2–7	27.52	24.78	19.24	22.95	21.41	23.18
	5–11	22.39	19.39	14.27	19.05	16.77	18.37
	Av.	24.95	22.09	17.25	21.00	19.09	20.78
150 lbs.	2–8	27.63	23.85	18.01	23.58	21.38	22.87
	5–10	21.93	18.96	13.93	17.48	15.40	17.52
	Av	24.78	21.40	16.97	20.53	18.35	20.20
		Potash					
0	1–6	26.44	22.17	16.44	20.81	19.83	21.14
	4–12	23.05	21.33	16.01	21.68	20.06	20.43
	Av.	24.74	21.75	16.22	21.24	19.94	20.78
40 lbs.	2–10	27.08	22.47	16.38	20.93	18.50	21.07
	5–8	25.58	23.46	19.38	22.80	21.59	22.56
	Av.	26.33	22.96	17.88	21.86	20.04	21.82
80 lbs.	2–11	26.23	22.46	15.74	20.77	19.21	20.88
	5–7	24.91	22.27	18.39	21.61	20.49	21.53
	Av.	25.57	22.36	17.06	21.19	19.85	21.21
120 lbs.	2–12	24.67	20.19	15.39	19.04	18.07	19.47
	5–6	23.68	20.51	15.94	20.39	18.77	19.86
	Av.	24.17	20.35	15.66	19.71	18.42	19.67
		Manure					
6–10–8, rye and vetch	6–7	25.19	22.69	17.66	21.79	20.96	21.36
	6–15	19.49	18.29	11.52	16.83	15.18	16.26
	Av.	22.38	20.49	14.59	19.31	18.07	18.95
10 tons and 6–10–8	6–3	26.99	22.23	17.37	21.03	19.16	21.35
	6–11	26.64	20.10	15.08	19.16	17.88	19.61
	Av.	26.81	21.16	16.17	20.09	18.52	20.56
20 tons	1–14	——	21.81	16.45	23.03	23.12	21.10*
	4–4	23.93	19.00	15.13	20.36	19.64	19.61
	Av.	——	20.40	15.79	21.69	21.38	20.36*
30 tons	1–15	27.45	23.07	16.07	22.89	21.60	22.34
	4–3	27.41	23.24	19.26	23.11	22.43	23.09
	Av.	27.43	23.15	17.98	23.00	22.01	22.72
40 tons	1–16	27.37	21.25	16.01	23.48	24.35	22.49
	4–2	32.09	27.42	22.63	26.04	24.61	26.74
	Av.	29.73	24.33	19.32	24.76	24.48	24.62

*These averages do not include a measurement on July 25, and thus are not

receiving different fertilizer treatments.

1929										
June 5	June 10	June 17	July 2	July 9	July 16	July 23	July 30	Aug. 6	Aug. 13	Average
					Nitrogen					
18.10	17.52	17.10	19.88	15.89	12.86	10.92	11.08	9.59	6.49	13.95
16.82	15.37	16.00	19.76	15.86	11.22	9.02	9.85	9.30	5.69	12.89
17.46	16.44	16.55	19.82	15.87	12.04	9.97	10.46	9.44	6.09	13.42
18.11	16.25	16.82	19.39	17.10	12.54	12.34	12.51	9.66	7.65	14.24
16.72	15.26	16.63	19.66	15.35	13.01	9.62	9.25	8.87	5.90	13.03
17.41	15.75	16.72	19.52	16.22	12.77	10.98	10.88	9.26	6.77	13.63
18.36	17.55	17.30	19.43	16.87	13.58	11.16	11.76	10.22	6.37	14.26
15.82	15.30	15.98	19.56	16.57	13.83	10.72	10.84	9.94	6.76	13.53
17.09	16.42	16.64	19.49	16.72	13.70	10.94	11.30	10.08	6.56	13.89
17.74	16.23	11.96	19.93	17.00	13.60	11.83	12.41	9.24	7.30	14.23
17.53	14.89	16.20	20.71	16.78	13.33	11.05	11.60	9.55	7.79	13.94
17.63	15.56	16.58	20.32	16.89	13.46	11.44	12.00	9.39	7.54	14.08
					Phosphorus					
17.76	16.36	16.37	19.67	17.49	13.89	12.89	12.31	11.11	7.65	14.55
15.03	14.74	14.94	18.01	15.20	12.50	10.87	12.99	11.87	8.54	13.48
16.39	15.55	15.60	18.84	16.34	13.14	11.93	12.65	11.49	8.09	15.01
18.84	17.43	17.70	20.52	17.71	14.58	10.33	11.43	8.85	6.88	14.43
17.05	15.68	17.46	21.25	16.93	13.30	12.23	11.94	10.72	7.60	14.42
17.44	16.55	17.58	20.88	17.32	13.94	11.28	11.68	9.78	7.24	14.42
20.47	18.06	19.03	22.12	18.50	13.40	12.54	11.44	9.15	7.03	15.18
15.26	14.75	14.32	18.63	14.86	11.98	8.84	9.42	8.55	6.16	12.28
17.36	16.40	16.67	20.37	16.68	12.69	10.64	10.43	8.85	6.59	13.73
20.35	18.35	19.49	21.88	18.05	15.84	12.11	11.96	10.56	6.37	15.50
15.80	16.05	14.37	18.43	14.76	11.64	9.33	10.32	9.22	6.26	12.62
18.07	17.20	16.93	20.15	16.40	13.74	10.72	11.14	9.89	6.31	14.06
					Potash					
19.15	17.64	18.12	21.27	17.78	14.16	10.27	11.29	9.09	6.10	14.53
18.20	16.95	17.46	20.36	16.84	12.65	9.10	10.65	9.46	6.51	13.82
18.67	17.29	17.88	20.81	17.31	13.41	9.68	10.97	9.27	6.30	14.17
19.29	16.69	17.62	20.35	17.46	12.72	9.83	11.40	8.53	6.34	14.03
19.18	18.36	17.60	20.52	17.02	12.99	11.49	10.63	10.72	7.38	14.50
19.23	17.52	17.61	20.43	17.24	12.85	10.66	11.01	9.62	6.86	14.31
18.08	16.36	17.34	19.70	16.79	12.25	12.52	11.87	10.78	6.16	14.19
17.14	15.16	16.44	18.73	16.32	12.56	10.94	10.29	9.73	5.81	13.28
17.61	16.76	16.89	19.21	16.55	12.40	11.73	11.08	10.25	5.98	13.73
16.86	16.13	17.66	19.65	17.34	13.94	10.97	12.06	9.56	7.59	14.10
17.53	14.98	15.14	18.73	15.78	13.18	10.62	10.48	9.52	6.16	13.22
17.24	15.55	16.40	19.19	16.56	13.56	10.79	11.27	9.54	6.87	13.63
					Manure					
18.56	15.48	16.86	20.02	16.14	14.43	10.22	11.33	9.28	6.66	13.91
14.24	12.30	13.28	15.96	13.46	10.10	8.08	9.20	7.68	5.09	10.94
16.40	13.89	15.07	17.99	14.82	12.26	9.15	10.26	8.48	5.87	12.42
18.78	16.73	16.76	19.94	16.47	13.63	11.95	11.97	10.23	7.42	14.43
17.54	16.14	16.69	19.87	17.08	12.68	11.55	12.01	10.45	6.88	14.09
18.16	16.43	16.72	19.90	16.77	13.15	11.75	11.99	10.34	7.15	14.21
19.71	19.01	20.40	21.04	18.99	15.02	13.71	12.30	9.28	6.63	15.61
19.96	19.15	18.32	21.42	18.15	13.60	9.62	10.54	9.52	6.32	14.47
19.83	19.08	19.36	21.23	18.57	14.31	11.66	11.44	9.40	6.47	15.08
21.44	19.45	22.23	23.78	22.55	15.98	15.00	14.42	11.26	7.80	17.27
23.05	20.11	20.52	23.68	20.57	16.32	11.40	12.28	11.22	7.12	16.63
22.24	19.78	21.37	23.70	21.56	16.15	13.20	13.35	11.24	7.46	16.95
21.44	20.83	21.27	21.65	20.04	14.97	15.06	14.49	13.37	8.36	17.15
26.91	24.59	23.36	23.71	25.80	18.86	15.87	15.79	13.75	9.09	19.77
24.17	22.71	22.31	22.68	22.92	16.91	15.46	15.14	13.56	8.72	18.46

strictly comparable with other averages.

in 1929. Also the averages in 1928 were higher than the highest individual measurement in 1929 on many plats. The range in 1928 was from 11.52% on plat 6–15 on August 21 to 32.09% on plat 4–2 on July 25. In 1929, the range was from 5.09% on plat 6–15 on August 13 to 26.91% on plat 4–2 on July 5. The plat with the lowest moisture percentage in 1928 was lowest also in 1929, and the plat with the highest moisture percentage in 1928 was also highest in 1929. While the range between extreme readings was greater in 1929 than in 1928, the differences between the lowest and highest averages for the two seasons were about the same, *viz.*, from 16.26% for plat 6–15 to 26.74% on plat 4–2 in 1928 and from 10.94 to 19.77% on the same plats, respectively, in 1929.

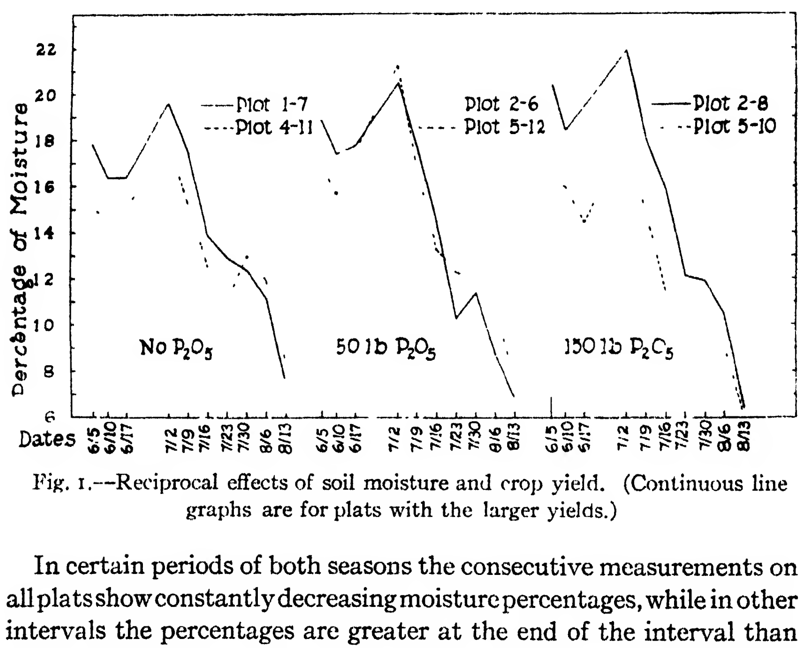

Fig. 1.—Reciprocal effects of soil moisture and crop yield. (Continuous line graphs are for plats with the larger yields.)

In certain periods of both seasons the consecutive measurements on all plats show constantly decreasing moisture percentages, while in other intervals the percentages are greater at the end of the interval than at the beginning. The latter relation indicates, of course, that precipitation had occurred during the interval between measurements, while the former indicates the usual reduction of moisture during periods in which either no rain had fallen or too little had been added to the soil to compensate for the losses occurring during the period.

The reduction in moisture percentage which occurred during the dry periods was not the same on all plats, and the increases in moisture percentage brought about by precipitation were likewise different on different plats. For example, the differences in moisture percentages between June 10 and June 17, 1929, ranged from a decrease

of 1.68% on plat 5–10 to an increase of 2.78% on plat 1–5. In 1929, a number of plats which were higher in moisture percentage than certain others at the time of the first measurements, and which were sometimes higher on the average, were as low as, or lower than, the others at the time of the last measurements taken during a prolonged period of dry weather. This was true of plats 1–7, 2–6, 2–7, 2–8, 6–7, 1–6, and 4–3 as compared with 4–11, 5–12, 5–10, 6–11, 4–12, and 1–15, respectively. These relations are shown graphically in Fig. 1 and are discussed somewhat more fully later.

The foregoing observations indicate that the different plats not only lost water at different rates, but also took up and held different amounts when precipitation occurred. Whether or not these differences were associated with the fertilizer treatments can be ascertained by a study of the differences in relation to the different quantities of each fertilizer element applied.

FERTILIZER TREATMENT AND MOISTURE

Nitrogen.—The first section of Table 3, including four pairs of plats and the averages of the pairs, presents the measurements of moisture percentage on the plats which differed from each other in respect to fertilizer treatment only in the amount of nitrogen applied. It will be seen that the average percentages of moisture on the duplicate plats are quite similar for the different treatments, the maximum difference being 1.59% between the averages for 0 and 30 pounds of nitrogen in 1928, and 0.66% between the averages for 0 and 90 pounds of nitrogen in 1929. These differences are evidently not significant, and they are not consistent for the two seasons nor for the same treatments.

In the nitrogen series, however, one of the two plats (4–10) receiving no nitrogen was consistently lower than the others. That this difference was not related to lack of nitrogen, however, is indicated by the fact that plat 1–8, the other plat receiving no nitrogen, was not consistently lower than any of the other plats in the series. The increases in moisture percentage in intervals during which rainfall evidently occurred were about the same for this plat as for the others. The rate of water loss, however, was greater, as shown by a comparison of plats 4–10 and 1–8 between July 2 and August 13, 1929. At the beginning of this period both plats had about the same percentage of moisture; after July 9, however, plat 4–10 was always lower in moisture than plat 1–8, though not always lower than other plats in the nitrogen series.

It is evident, therefore, that differences in moisture percentages of

plats in the nitrogen series are not associated in any measurable way with the fertilizer applications which the plats received.

Phosphorus.—The average moisture percentages of duplicate plats in the series receiving different amounts of phosphoric acid (Table 3) show no consistent differences which may be associated with the amount of phosphoric acid received. As in the case of plats in the nitrogen series, however, there were significant differences between the moisture percentages of plats receiving like applications of phosphorus. Plat 1–7 (no P_2O_5), for example, had a higher moisture percentage than plat 4–11, except for the three measurements after July 23, 1929; plat 2–7 (100 lbs. P_2O_5) and Plat 2–8 (150 lbs. P_2O_5) were always above plats 5–11 and 5–10 which received like treatments, respectively. Plats 5–10 and 5–11 were lowest in moisture percentage in both seasons, while the respective plats with like treatments 2–8 and 2–7 were the highest in the series.

It is thus apparent with phosphorus, as with nitrogen, that the differences in moisture percentage between plats in the phosphorus series were not associated with the amounts of phosphorus applied.

Potassium.—The maximum difference between the average moisture percentages of duplicate plats in the potash series was 2.15 in 1928 and 0.68 in 1929. The plats receiving potash at the rate of 40 pounds to the acre (2–10 and 5–8) had the highest average moisture percentage in both seasons, while those receiving potash at the rate of 120 pounds to the acre (2–12 and 5–6) were lowest in both seasons. An examination of the separate plats, however, shows that plat 5–8 (40 lbs. K_2O) had a greater average percentage of moisture in both seasons than its duplicate, plat 2–10. The moisture percentage of plat 5–8 was greater than that of plat 2–10 at all times in both seasons except on July 25 in 1928 and June 5, June 17, and July 9 in 1929. Plat 1–6 (no K_2O) had a consistently greater moisture percentage in 1929 than did plat 4–12 which received the same treatment. The difference between the average percentages of these two plats for the season was greater than the maximum difference between the averages for the different treatments. In 1928, however, the differences between the moisture percentages of plats 1–6 and 4–12 were not consistent on the different dates of measurement, and the difference between the average percentages of these two plats for the season was not significant. Furthermore, the order of the average moisture percentages for the different treatments was not the same in both seasons. Although the treatments which were highest and lowest with respect to moisture percentage were the same, the order of the two treatments was different in the two seasons. In view of the fact

that the differences between treatments were small and in consideration of the inconsistencies just pointed out, it seems doubtful that the differences in moisture percentages of plats in this series were associated with the amount of potash received.

Barnyard manure.—The average moisture percentages for the plats receiving different amounts of barnyard manure (Table 3) were consistently greater for greater amounts of manure. This is true for both seasons, with the exception of the average for the two plats receiving 20 tons of manure to the acre. The average for plat 1–14 (20 tons), however, did not include a measurement of moisture percentage on July 25, since this was lost. This would very likely have raised the average considerably. It must be remembered that the averages of plats 1–14 and 4–4 are not comparable with those of plats 6–3 and 6–11 on the basis of manure application only, since the latter two plats received complete fertilizer in addition to 10 tons of barnyard manure, while the former two received 20 tons of manure only.

If the moisture percentages of the separate plats are studied, however, it will be noted that the differences between the moisture percentages on the various dates of plats 4–3 (20 tons), 6–3 (10 tons), 6–7 (no manure), and 6–11 (10 tons) were small and variable. Plat 6–15 (no manure) is noteworthy as having had the lowest moisture percentage of any plat studied on nearly all of the dates when measurements were made. Plat 1–14 (20 tons) was somewhat above plat 4–4, which received the same treatment. This difference, however, serves only to indicate the lack of significance of the differences between the plats just mentioned.

If the plats receiving manure at the rate of 30 or 40 tons to the acre are compared with those receiving lesser amounts, the differences in moisture percentage are fairly large and consistent. A comparison by Student's method (6, 7) of the moisture percentages on the various dates in both seasons of plats 1–16 and 1–14 shows that the odds are approximately 624 to 1 that the difference between the averages, 1.17%, is not a matter of chance. These plats are chosen as being respectively the lowest of the plats receiving 30 tons or more of manure to the acre and the highest of those receiving 20 tons or less in respect to the average percentage of moisture for both seasons. The effect of the manure in bringing about these differences may be seen in the proportionally greater differences in favor of the heavy applications of manure in 1929, and especially in the very dry period at the time of the last measurements in 1929 as compared with 1928. In 1929, for example, the average difference between the moisture

percentages of these two plats on the different dates was 1.54, and the odds that this difference was not due to chance were approximately 1,175 to 1.

The average percentages of moisture of the two plats receiving manure at the rate of 40 tons to the acre were always higher than those of the two plats receiving 30 tons, except on July 2, 1929. If these average percentages are compared by Student's method, the significance of the difference between them is established beyond question, the odds being above 10,000 to 1. If the plats receiving 40 tons of manure to the acre, namely, 1–16 and 4–2, be compared individually with the adjacent plats receiving 30 tons of manure, namely, 1–15 and 4–3, respectively, the odds are found to be over 1,000 to 1 that the difference is significant.

It is thus established that manure in large amounts exerted a favorable influence in increasing the percentage of moisture in the the soil. The effect of manure in increasing the soil moisture content of these plats is shown further by comparing the average moisture percentages of eight plats which received barnyard manure in amounts from 10 to 40 tons to the acre (the 10-ton applications being supplemented with 1,000 pounds of 6–10–8 commercial fertilizer) with those of eight other plats all of which received 1,000 pounds of 6–10–8 commercial fertilizer without barnyard manure.

The plats thus compared are 1–14, 1–15, 1–16, 4–2, 4–3, 4–4, 6–3, and 6–11 for the manured plats and 2–3, 2–7, 2–11, 5–7, 5–11, 5–15, 6–7, and 6–15 for the commercial fertilizer plats. In 1928, the mean of the seasonal average moisture percentage of the former group of plats was 22.04 $\pm$ 0.617%; that of the latter group of plats 20.28 $\pm$ 0.721%; the difference being 1.76 $\pm$ 0.949% in favor of the plats receiving applications of barnyard manure. Since in this case the mean difference between the moisture percentages of the plats is less than three times its probable error, this difference cannot be considered as particularly significant. In 1929, which was relatively dry as a whole and very dry at the end of the season, the respective mean moisture percentages for the manure plats and the commercial fertilizer plats were 16.18 $\pm$ 0.456 and 13.45 $\pm$ 0.314 and the difference between them 2.73 $\pm$ 0.554. The difference in this season, therefore, was clearly significant.

MOISTURE AND CROP YIELDS

The importance of moisture in determining crop yields is suggested in the case of plats 5–10 (150 lbs. P_2O_5) and 5–11 (100 lbs. P_2O_5), both of which produced lower yields than plat 2–6 (50 lbs. P_2O_5).

This result is not in agreement with the results from the experiment as a whole, which indicate that the larger the quantities of phosphoric acid applied, the greater are the crop yields. The significance of this discrepancy is greatly reduced by the fact that the average moisture percentages of plats 5–10 and 5–11 were considerably lower than that of plat 2–6 in both seasons. In fact, the plats in the phosphorus series (Table 3) which had distinctly lower average moisture percentages than the plats which received the same fertilizer treatment were likewise distinctly lower in the yield of the particular crop which was growing on them in the given season (corn in 1928 and cabbage in 1929) and also in the average yields of all crops (Table 2). This is true for plats 4–11 (no P_2O_5), 5–11 (100 lbs. P_2O_5), and 5–10 (150 lbs. P_2O_5) as compared with plats 1–7, 2–7, and 2–8, respectively. This same relation is evident, also, with plat 6–15 as compared with plat 6–7 and with plat 1–16 as compared with plat 4–2. Both the moisture percentages and the average crop yields of plats 6–15 and 1–16 were lower than those of plats 6–7 and 4–2 which received the same fertilizer treatments, respectively.

Such comparisons as the foregoing indicate that natural moisture differences are important conditions in determining crop yields. The relative importance of moisture as compared with other conditions cannot be shown by this method of analysis, however, because of the limited number of comparisons which can be made.

A study of moisture and yield by the method of correlation, as discussed by Babcock and Clausen (1) and by Sinnott and Dunn (10) points out certain noteworthy relationships. The coefficient of correlation among the average percentages of moisture of the various plats in 1929 and the respective yields of cabbage in the same season was $.467 \pm .089$. Since the probable error is slightly more than one-sixth of the coefficient of correlation, the significance of this value is not beyond question.

Several conditions would be expected to reduce the coefficient of correlation in the above case. One of these is the variation in amount and character of the fertilizer treatments given the different plats. Another is illustrated by certain plats in the phosphorus series. At the beginning of the season these were distinctly lower in moisture content than the others which had received like treatments, but were nearly equal to them in moisture content at the end of the season and in some cases were higher (Table 3, plats 1–7 and 4–11, 2–6 and 5–12, 2–8 and 5–10). These relations are also shown in the graphs in Fig. 1. Within the pairs, the plats which had the higher moisture percentages at the beginning of the season also had the higher yields (Table

3). It is probable that the larger crops with their greater water demand were responsible for the proportionally greater reduction in moisture percentage on the plats which produced them. In this manner, large crops which were produced on plats with high moisture percentages tended to reduce the difference between plats in this respect, particularly if the supply of moisture were not renewed.

Under such circumstances, a higher correlation might be expected between the crop yields and the moisture percentages early in the season before differences in crop yields had disturbed the relations between the moisture percentages of the different plats. The coefficient of correlation between cabbage yields in 1929 and the average moisture percentage of the respective plats during the first three week (June 5-17) was .492 ± .087. This value is scarcely significant, though it is slightly greater than that between the cabbage yields and the average moisture percentage for the whole season. The coefficient of correlation of the yields of sweet corn and the average moisture percentages in 1928 was found to be .400 ± .097. The lack of significance of this correlation is to be expected, however, in view of the conditions prevailing in 1928. Rainfall occurred so frequently that it was practically impossible to control the weeds and as a result the yields of sweet corn were small and highly variable. It is likely that in many cases plats which usually produced good crops, yielded small crops in this season because of excessive moisture.

When the average relative yields of all the crops grown on the plats under study are correlated with the average moisture percentage of the respective plats, however, significant coefficients of correlation are found. The values for 1928 and 1929 are, respectively, .601 ± .0735 and .792 ± .042. These values indicate that the influence of moisture was probably greater than that of any other condition in determining the yields of the crops on the plats studied.

ORGANIC MATTER CONTENT OF THE PLATS

Measurements were made of the organic matter in the soils of the various plats in order to find its relation to soil moisture. The results of these measurements are presented in Table 4. An examination of the organic matter percentages of the different plats and the fertilizer treatments which they received fails to show any consistent relation between the amounts of organic matter and the quantities of the different commercial fertilizer elements applied, except possibly in the case of potash, where the smaller applications are associated with the larger percentage of organic matter. The significance of this relation, however, cannot be estimated. In the manure series,

the greater percentages of organic matter are associated with the heavier applications of manure, and the relation is fairly consistent.

TABLE 4.—*Total organic matter content of plats receiving different fertilizer treatments.*

Treatment per acre	Plat No.	Percentage of organic matter (organic C x 1.724)
	Nitrogen Series	
0	1–8	4.714
	4–10	5.136
30 lbs.	2–2	4.076
	5–16	3.246
60 lbs.	2–3	3.386
	5–15	3.117
90 lbs.	2–4	3.297
	5–14	4.479
	Phosphoric Acid Series	
0	1–7	3.833
	4–11	3.698
50 lbs.	2–6	4.081
	5–12	3.840
100 lbs.	2–7	5.260
	5–11	3.558
150 lbs.	2–8	5.040
	5–10	2.810
	Potash Series	
0	1–6	4.177
	4–12	4.760
40 lbs.	2–10	4.029
	5–8	3.967
80 lbs.	2–11	3.908
	5–7	3.483
120 lbs.	2–12	3.115
	5–6	3.474
	Manure Series	
0 and 6–10–8	6–7	3.441
	6–15	2.690
10 tons and 6–10–8	6–3	3.596
	6–11	3.515
20 tons	1–14	4.946
	4–4	4.824
30 tons	1–15	5.455
	4–3	5.408
40 tons	1–16	5.541
	4–2	5.970

ORGANIC MATTER, SOIL MOISTURE, AND CROP YIELDS

The coefficient of correlation between organic matter percentages and the average moisture percentages of the respective plats in 1928 was .618 ± .0715; that between the organic matter and the average moisture percentages in 1929, .793 ± .043; and that between the organic matter and the average of the first three measurements of moisture percentage in 1929, .845 ± .030. The soil moisture content of these plats and their organic matter content are thus shown to have

been very highly correlated, especially at the time when the relations between the moisture percentages were little influenced by crops growing on the plats.

The percentages of organic matter and the crop yields also are found by this method of examination to be associated to a considerable extent. The coefficient of correlation between the yields of cabbage in 1929 and the organic matter percentage of the respective plats is .517 ± .085; that between yields of sweet corn in 1928 and organic matter percentages, .625 ± .071; and that between the average relative yields of all crops and organic matter percentage, .665 ± .064. The crop yields, organic matter, and soil moisture of the different plats are thus seen to be related to a highly significant degree.

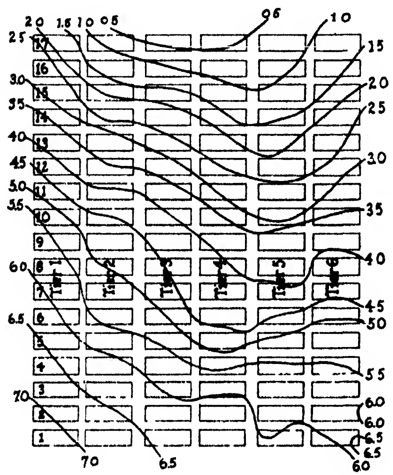

Fig. 2.—Contour map of plats. (Intervals of 0.05 ft.)

SOIL MOISTURE AND TOPOGRAPHY

It seems probable that the relations pointed out above may be characteristics of the plats which have been modified but little since the beginning of the experiment. A fact which indicates this is that the coefficients of correlation between organic matter and crop yields and between soil moisture and crop yields are greater for the averages of all crops throughout the period of the experiment than for the particular years in which soil moisture and organic matter were measured.

If this be the case, it should be possible to find other characteristics of the plats in question which might account for the differences described above. Such characteristics would have to account only for the differences in moisture content of the plats. The differences in crop yields and through these the differences in crop residues and organic matter might readily follow as the result of differences in moisture supply. The gross physical characteristics of the plats which affect the absorption of water during periods of precipitation obviously are as likely to cause differences in the moisture content of plats as are conditions which influence the rate of water loss. Of the conditions affecting absorption of moisture, topography as influencing

surface drainage and soil texture as influencing rate of entrance of water into the soil are among the most important.

The plats which were conspicuously low in average moisture content as compared to others receiving like fertilizer applications were usually situated in such a way that surface drainage occurred readily (Fig. 2). Plats 1–16, 5–10, 5–11, 5–12, and 6–15 have surfaces which are noticeably more sloping than the respective plats receiving like fertilizer treatments, *viz.*, plats 4–2, 2–8, 2–7, 2–6, and 6–7. On the other hand, several plats which were conspicuously high in moisture percentage, yield, and organic matter are in a position to derive benefit from the surface drainage of higher plats situated next to them Examples of such plats were 4–2 and 4–3.

The soil color of certain plats which were distinctly low in moisture, especially that of plat 6–15, is noticeably more yellow than that of other plats. This yellow color has been found by general observation to be associated with a relatively shallow soil mantle and a high percentage of clay.

SUMMARY AND CONCLUSIONS

The foregoing discussion deals with the relations between fertilizer treatment, soil moisture, organic matter, and crop yields. The data on which the discussions are based are the measurements of soil moisture percentage on certain plats at various intervals during part of the growing seasons of 1928 and 1929, the percentages of humus in the soil of these plats, the crop yields of the plats throughout the period during which they had been under experiment (12 years), and the fertilizer treatments which had been given to the plats. The following relations have been pointed out:

1. There was no apparent association between the amounts of the different commercial fertilizers and the percentages of soil moisture or of organic matter.

2. The only fertilizer treatments which had a significant influence on soil moisture and organic matter were heavy applications of barnyard manure.

3. The crop yields were correlated to a significant degree with soil moisture without regard to the different fertilizers applied. The relative soil moisture was one of the very important conditions influencing crop yields—possibly the most important.

4. The percentages of soil organic matter and moisture were correlated to a significant degree with each other and with crop yields.

5. The correlation between the yields of all crops during the period of the experiment and the average percentages of soil moisture

is greater than that between the average percentages of soil moisture in a particular season and the yields of the crops grown in the same season. This indicates that the relative crop yields and the soil moisture were characteristics of the plats studied which did not change greatly in their relation to each other during the period of the experiment.

6. The topography as it affected surface drainage is suggested as one of the physical features which might have had an important influence on the moisture content of the plats.

It is to be emphasized that causal relationships between the various conditions have not been pointed out in this discussion. It has not been shown, for example, whether differences in the percentage of organic matter brought about the differences in the percentage of soil moisture or whether the differences in soil moisture which were characteristic of the plats resulted in different percentages of organic matter through greater crop residues. It may safely be assumed, however, that differences in soil moisture brought about differences in crop yield. The degree of association between these two factors, as shown by the coefficient of correlation between them, indicates that the influence of natural differences in soil moisture in determining the crop yields was very great.

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THE RELATIVE EFFECT OF SINGLE AND FRACTIONAL APPLICATIONS OF SOLUBLE NITROGEN ON NITRATES IN SOIL AND PLANT AND ON THE YIELDS OF CERTAIN VEGETABLE CROPS[1]

JOHN B. SMITH, FRED K. CRANDALL, and DONALD E. FREAR[2]

The efficiency of single applications of soluble nitrogen at planting time has been compared frequently with that of fractional applications supplying an equal amount of nitrogen during the growth of the crop, but inconsistent results make general conclusions difficult. In Table 1, a summary of 65 published trials by many workers[3], 3 or more for each of 14 different crops, shows consistent results for only 2, and further trials conceivably might produce conflicting evidence for these It is interesting, but not conclusive, that the preponderance of evidence favors single applications for sugar beets, mangels, rye, tobacco, and spring wheat; fractional applications for cabbage, celery, corn, cotton, tomatoes, and turnips; but that for barley, oats, and potatoes there are an equal number of trials in favor of both methods of application, and nearly as many trials failed to show significant differences between the two methods. The important fact is the obvious effect of climatic and soil variations in causing variance either in the nitrogen requirements of the crop or in the rate of supply of that element by the soil.

As evidence of this, Anderson and Swanback (1)[4] state that fractional applications of nitrogen for tobacco first became beneficial in an extremely wet season after a series of years when single applications had produced slightly better yields, and ascribe the benefit to the replacement of nitrogen lost by leaching.

More recently Brown, Owen, and Tobey (3) state that for potatoes in Maine, "It is likely that delayed top dressing may be a wise practice during exceptional seasons, but it is not nearly so important a problem in Aroostock County as under soil conditions where leaching is generally serious."

The object of this paper is to present the results of further field comparisons of these two methods of applying nitrogen, especially for

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[2]Chemist, Assistant Agronomist, and former Assistant Chemist, respectively.

[3]Data from abstracts in Experiment Station Record, 1889–1930.

[4]Reference by number is to "Literature Cited," p. 221.

vegetable crops, and to show the advantages of a knowledge of the fluctuation of certain forms of nitrogen in the soil and plant as an aid to interpretation of differences in yields.

TABLE 1.—*Summary of 65 published trials* of the relative efficiency of a single application of soluble nitrogen at planting time vs. fractional applications of an equal total quantity during the growth of the crop.*

Crop	Number of trials favorable to different methods of application		
	Single application	Fractional applications	Difference insignificant
Barley	1	1	1
Beets, sugar and mangel	6	2	2
Cabbage	1	3	1
Celery	–	3	–
Corn	1	2	–
Cotton	1	5	–
Oats	3	3	2
Potatoes	3	3	2
Rye	2	–	1
Tobacco	3	1	1
Tomatoes	1	4	–
Turnips	–	3	–
Wheat, spring	2	–	1
Total	24	30	11

*Assembled from abstracts in the Experiment Station Record, 1889-1930.

EXPERIMENTAL METHODS

AGRONOMIC METHODS

For the purpose of the experiment, the soils and crops of a market-garden rotation (W) were chosen. This rotation—lettuce, cabbage, and tomatoes in the spring followed, respectively, by celery, beets, and spinach in the fall—was last described by Hartwell and Crandall (8), and certain relationships between the nitrates of the soil and plant have been discussed by Gilbert and Smith (6, 9).

The soil, Merrimac silt loam, is normally very acid, but the area studied has been limed to neutrality. The surface layer is underlain by a plastic yellow loam that resists leaching. The 1/30-acre plats chosen are those that have received the standard treatment, 16 tons of manure per acre each spring from 1916 to 1927, since which time 20 tons of a compost of vegetable refuse with horse stable manure has been used in the lettuce-celery year and 12 tons before the tomatoes-spinach. The manure has been supplemented by a complete fertilizer for each crop, the combined treatment being chosen to produce a satisfactory crop, although not necessarily the maximum. In recent years manganese sulfate has been included in the fertilizer to prevent a lime-induced chlorosis that has given trouble on this soil.

The experiment was conducted during 1929 and 1930. The plats chosen were divided in half. To one half, the total quantity of nitrogen for the crop was harrowed in before planting. For the other half an equal amount was divided among three or four applications, one to be applied before planting except for celery and the remainder distributed later as side-dressings. Most of the nitrogen was supplied by a mixture containing 1 part of nitrogen in nitrate of soda and 2 parts in sulfate of ammonia, but cabbage and tomatoes received small quantities of tankage in the initial application. The side-dressings were applied by hand, placing the fertilizer salts in a rather wide layer near the plants

Onions were grown in a different rotation (A). This rotation is manured lightly once in each 5-year round. A 2/15-acre plat was divided in half to provide for the two types of fertilization. Optimum quantities of superphosphate and potash carriers were supplemented by equal parts of nitrogen from nitrate of soda and sulfate of ammonia, the latter being used first for the fractional treatment.

All agronomic data in this paper are reported on the acre basis.

CHEMICAL METHODS

Nitrate nitrogen in the soil was determined by the phenoldisulfonic acid method described by Harper (7), using composite samples of 25 cores of soil for each 1/60-acre area. Fifty borings to 1/30 acre have been shown to reduce the probable error of the determination to within ± 5% of the values reported for these conditions (2). The samples were taken at weekly intervals in 1929 and each fortnight during the cropping season of 1930. Usually two samples were taken to represent each area, one from the upper 7-inch layer and one from the second 7-inch layer. The results from the two layers have been averaged, when both were available, to simplify the presentation of the data and to avoid the minor fluctuations caused by water movements in the top soil. Moisture was determined in all samples by drying at 105° C, and the results are presented as p. p. m. of nitrogen in oven-dry soil.

Soil ammonia was determined from time to time, but the results verified previous conclusions that the rate of nitrification or the absorption of ammonium nitrogen by crops and micro-organisms in these fertile, well-limed soils is so rapid as to prevent any significant accumulation of that form of nitrogen.

Nitrate and alpha-amino nitrogen were determined in the juice expressed from leaves of the 1929 crop. After the plants had reached sufficient size, 20 to 50 leaves or leaflets were taken each week, using

care to select leaves of a uniform size approximating the average for the area sampled. The midribs were removed, as it has been shown in this laboratory (5) that juice from the midribs is more concentrated with respect to nitrates than is that from the remainder of the leaf, and it was desired to restrict the analysis as closely as practicable to the tissue most affected by photosynthesis.

The leaf tissue was frozen by contact with solid carbon dioxide, thawed, and the juice expressed at a pressure of 1,000 pounds per square inch. Clarification of the juice and the determination of nitrate nitrogen was accomplished as described by Frear (4). Alpha-amino nitrogen was determined in the unclarified juice by the usual Van Slyke method but without previous removal of the free ammonia. A portion of the ammonia nitrogen is measured as amino nitrogen by the method used, so that the results are somewhat in error. The ammonia nitrogen, however, as determined for each sample by aspiration, varied but little for the treatments compared, and the total seldom exceeded 100 p. p. m. As only a portion reacts during the short time that the juice is in contact with the reagents, the error is not considered sufficiently large to destroy the comparisons.

Ammonium nitrogen was determined each week, but revealed no consistent differences between the crops compared.

CROP MEASUREMENTS

The heights and widths of 20 to 50 plants, selected from each 1/60-acre area in accordance with a regular pattern, were measured weekly. To reduce the measurements to a single value and to increase the uniformity of the data, the height of each plant was multiplied by the width, giving the area of a verticle rectangle corresponding roughly to the cross-section of the plant. Statistical analysis of the products showed probable errors for the means that were less than $\pm$ 5% of the means. Space does not permit publication of the data, but reference will be made to differences between the comparisons that calculation by the usual statistical formula have shown to be significant.

WEATHER

The rainfall during the cropping season of 1929 was ample, although not distributed uniformly. Approximately 8 inches fell in April, 7.5 inches between May 1 and August 12, and 10 inches thereafter, making a wet spring and fall but a dry summer. The 1930 season was decidedly dry throughout, but especially after midsummer. For the periods selected arbitrarily for 1929, and noted above, there was less than 1.5 inches in April, 9 inches between May 1 and August 12, and only 4 inches between August 12 and October 23.

Soil moistures on sampling dates in 1929 ranged between 17.7% and 27.0% for the manured soils and 15.3% and 25.5% for the onion plat. In 1930 the corresponding results were 13.2% and 22.6% for manured soils and 13.3% and 20.5% for soil under onions.

TABLE 2.—*Planting, nitrogen fertilization, and harvest data for the crops studied, all data calculated to the acre basis.*

Planting date	Initial N fertilization in pounds	N in side-dressings	Harvest date	Yields*
		Onions		
Apr. 3, 1929	80		Aug. 27–Aug. 29	607.8
Apr. 3, 1929	20	40 lbs. June 25; 20 lbs. July 19	Aug. 27–Aug. 29	471.6
Apr. 3, 1930	80		Aug. 23	546.3
Apr. 3, 1930	20	20 lbs. May 24, June 23, July 25	Aug. 23	521.7
		Cabbage		
Apr. 24, 1929	120		July 1–July 22	510.0
Apr. 24, 1929	40	40 lbs. June 10, June 24	July 1–July 22	525.0
Apr. 14, 1930	120		June 23–July 15	613.0
Apr. 14, 1930	40	40 lbs. May 16, June 7	June 23–July 15	640.0
		Tomatoes		
May 27, 1929	60		July 19–Aug. 16	388.5
May 27, 1929	20	20 lbs. July 6, Aug. 3	July 19–Aug. 16	322.7
May 20, 1930	75		July 15–Aug. 26	654.2
May 20, 1930	37	38 lbs. July 3	July 15–Aug. 26	635.8
		Celery		
July 12, 1929	90	22.5 lbs. Aug. 9, Aug. 23, Sept. 10, Sept. 23	Oct. 21–Oct. 30	115.8
July 12, 1929	0		Oct. 21–Oct. 30	150.6
June 24, 1930	90		Oct. 16–Oct. 20	241.2
June 24, 1930	0	22.5 lbs. July 22, Aug. 9, Aug. 28, Sept. 10	Oct. 16–Oct. 20	211.2
		Beets		
July 27, 1929	75		Oct. 16–Oct. 18	164.4
July 27, 1929	18	19 lbs. Sept. 10, Sept. 24, Oct. 2	Oct. 16–Oct. 18	126.0
July 23, 1930	75		Oct. 13–Oct. 22	391.2
July 23, 1930	25	25 lbs. Sept. 5, Sept. 19	Oct. 13–Oct. 22	387.6
		Spinach		
Aug. 22, 1929	75		Oct. 25	920.0
Aug. 22, 1929	18	19 lbs. Sept. 24, Oct. 2, Oct. 11	Oct. 25	1,420.0
Aug. 29, 1930	75		Oct. 15–Oct. 17	1,980.0
Aug. 29, 1930	25	25 lbs. Sept. 19, Oct. 3	Oct. 15–Oct. 17	1,980.0

*Onions in bushels (50 lbs.); cabbage in barrels (80 lbs.); tomatoes in bushels (56 lbs.); celery in hundred weights (trimmed); beet roots in bushels (50 lbs.); spinach in bushels (12 lbs.).

As might be expected, the dry season of 1930 was unusually warm. Monthly averages of temperatures read between 6 and 7 a. m. in the upper 3 inches of an unshaded soil area where 3.4° to 3.9°F higher for May, June, July, and August in 1930 than in 1929. For the month of September and the first 3 weeks in October the differences were 6.3° and 6.6° F, respectively.

Despite the drier soils of 1930, harvest weights were greater than in 1929, except for onions grown with a single application of nitrogen.

DISCUSSION OF RESULTS

Planting dates, data with regard to nitrogen fertilization, and yields are reported in Table 2. The results for soil nitrates and analyses of plant juice are reported graphically for the individual crops.

ONIONS

Southport Yellow Globe onions were grown from seed planted on April 3 of both years. The fertilizer nitrogen was obtained one-half from sulfate of ammonia and one-half from nitrate of soda. A satisfactory stand was secured in 1929 and an unusually thick stand of seedlings in 1930. In the first season the crop produced mature bulbs of good quality, but in 1930 dry soil and thrip injury killed the tops prematurely and less than two-thirds of the bulbs reached normal size. The yields for the single and for the fractional applications of nitrogen in 1929 were 607.8 bushels and 471.6 bushels, respectively; in 1930, 546.3 bushels and 521.7 bushels. The more rapid growth of the seedlings on the single-application area in 1929 was observable early. One hundred plants selected at random on July 29 weighed 10% more than an equal number from the comparison area. In 1930, however, no difference could be observed in the growth rates and the yields were substantially alike.

Nitrate nitrogen determinations in the upper 7 inches of soil furnish the only available evidence of the rates at which the two methods of application presented nitrogen to the plants (Fig. 1). The rain charts placed upon the graph showing the nitrate nitrogen concentrations show little evidence of leaching, except for the heavy rain just before harvest in 1929; but the 8 inches of rain in April of that year undoubtedly removed much of the nitrogen of the initial applications temporarily and this accounts for the low nitrate levels during the early part of that season.

The important facts noted from a study of the results for soil nitrates are, first, the remarkable parallelism between the curves for the two treatments compared and the relatively small effect of side-

dressings of 20 to 40 pounds of soluble nitrogen on the course of nitrate fluctuations from natural causes; and, second, the persistence of the higher nitrate concentrations initiated by the single application until quite late in the growth period, presumably creating an advantage for the crop.

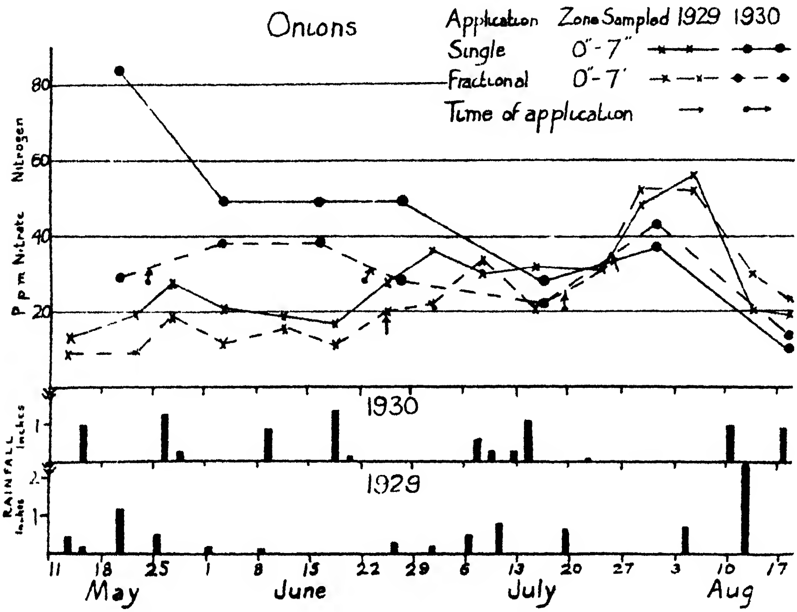

FIG. 1.—Nitrate nitrogen in the soil under onions.

Apparently the low levels of nitrates following the heavy rains of April, 1929, made the small differences observed between the two treatments important, for the higher level accompanied a decidedly better yield. Although the corresponding differences were greater in the succeeding year, the lower level of that season was well above the high level of 1929 for a considerable portion of the season, and may well have been sufficient. If so, the greater concentrations from the single treatment in 1930 may have been superfluous. This cannot be shown conclusively as the crop did not mature fully, but at the time of harvest the difference between the yields could not be considered significant.

All of the evidence available for onions advocates the practice of a single fertilizer application before planting.

CABBAGE AND BEETS

Golden Acre cabbage plants set in April were harvested before the third week in July. These were followed immediately by a crop of

Early Wonder beets which were allowed to grow until the advent of killing frosts in October.

The cabbages grew vigorously and produced satisfactory yields, *viz.*, 510 barrels and 525 barrels of heads for the single and fractional applications, respectively, in 1929; 613 barrels and 640 barrels for a similar comparison in 1930. Crop measurements made each week in 1929 revealed no significant differences between the growth rates for the two treatments, and the total nitrogen in the above-ground portion of the plants was 3.20% for the single application, and 3.19% for the fractional application. The first cutting in 1929, July 1 to 5, was greater by 12 barrels for the single application, but this was offset by an excess of 16 barrels from the fractional treatment at the second cutting. Beginning June 23, 1930, the single application produced for the first three cuttings excesses over the fractional applications of 2.6, 9.5, and 17 barrels, respectively. The differences between the total yields from the two methods of fertilization are insignificant, but the single application gave slightly earlier maturity.

The similarity in yields and growth curves show that differences in soil and plant created by the two methods of fertilization were not sufficient to affect the crop, and must be studied from that point of view. If only differences greater than 5 p. p. m. of nitrate nitrogen on the basis of dry soil be considered significant, it may be seen from the graph showing concentrations of this nutrient in the upper 14-inch layer (Fig. 2) that this difference was exceeded only on one sampling date in each of the 2 years. The nitrates provided by the two types of fertilization were approximately equal throughout most of the growth of the crop.

The results confirm the observation made for onions that the heavy rains in April, 1929, removed a considerable portion of the initial nitrogen applications. The persistence of the nitrate level from the single application, despite withdrawals by the growing crop, indicates that the removal may have been temporary. If this assumption is correct the excess return of the nitrates from greater soil depths in the single-application area was almost balanced by the side-dressings applied to the comparison area. Permanent losses would probably have increased the effectiveness of side-dressings.

Greater differences than those in the soil are presented by the determinations of nitrate and alpha-amino nitrogen in the plant juice for the 1929 crop (Fig. 3). The plants grown with a single application had the greater accumulations of nitrates throughout the sampling period, although the differences were small after the second week in June. On the other hand, the amino fraction was generally

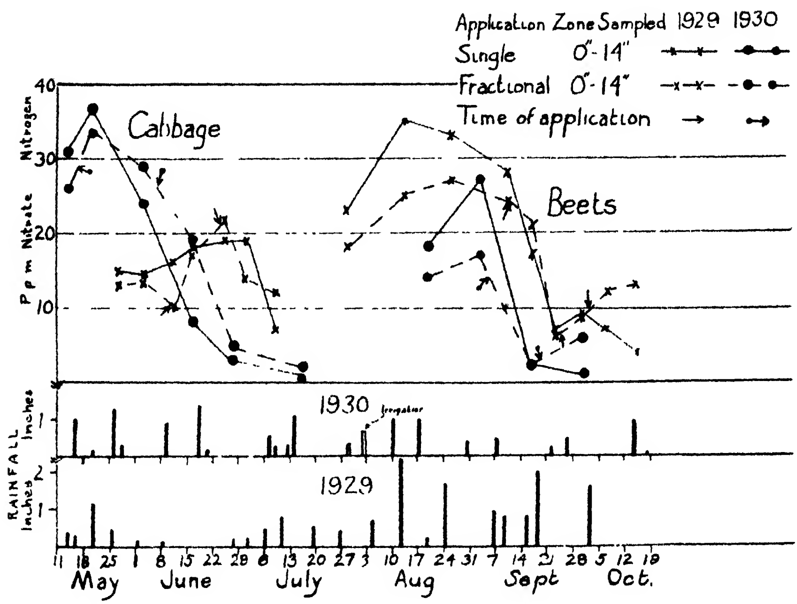

FIG. 2.—Nitrate nitrogen in the soil under cabbage and beets.

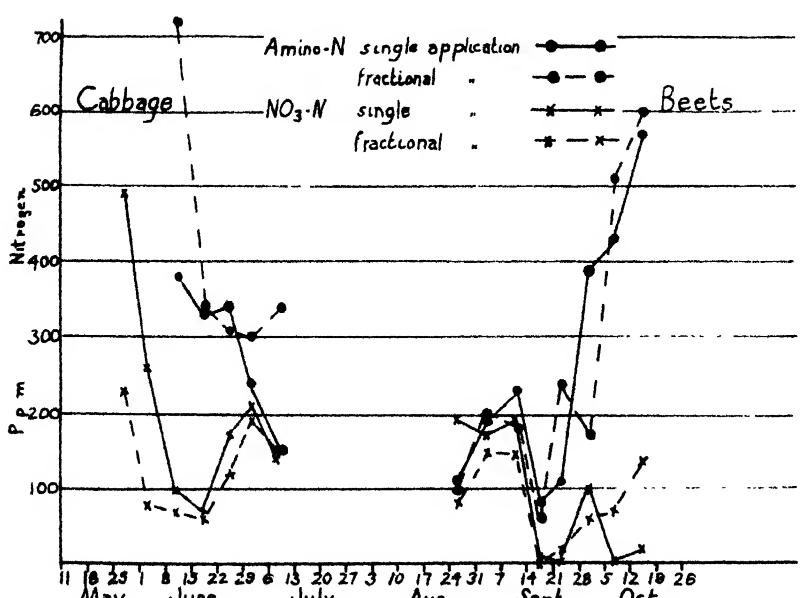

FIG. 3.—Nitrate and alpha-amino nitrogen in the juice from the leaves of beets and cabbage, midribs excluded, 1929 crop.

greater in the plants from the fractional area, so that the apparent advantage to protein metabolism of greater nitrate accumulation in one crop was offset by greater concentrations of amino nitrogen in the other. Other work at this station has shown a general tendency toward a positive correlation between nitrate and alpha-amino nitrogen in plant juice, but the inverse relationship noted above occurs with considerable frequency. For two crops in a similar environment, except for the nitrogen supply, it is logical to expect all nitrogen fractions to be greater in the juice of the plants receiving the more nitrogen, and the reasons for a negative correlation are not clear. The differences noted were without apparent effect on the growth of cabbage.

The yields of beet roots from the crops following cabbage were 164.4 bushels and 126.0 bushels from the single and fractional applications, respectively, in 1929; 391.2 bushels and 387.6 bushels in 1930. The 1929 yields were unsatisfactory, but the single application produced a much larger yield than did the side-dressings. In the following year, the yields were normal and the two methods of fertilization proved equally effective. Weekly measurements of the vegetative portions of the 1929 crop showed a significantly better start from the single application, and that the advantage was maintained until October 5 when gains by the smaller crop brought both to approximately equal size. Frosts in mid-October prevented the gain in weight of roots that would probably have followed the gain in vegetation.

Nitrate-nitrogen concentrations in the upper 14 inches of soil under the crops failed to explain the small yields of 1929, as the nitrate accumulations were uniformly greater in that season than under the better crops of 1930 (Fig. 2). It is clear, however, that the large single application furnished more nitrogen to the crop until the middle of September, after which the side-dressings gave the advantage to the crop receiving the fractional applications. In 1930, the differences between the two treatments were somewhat similar but not sufficient to affect the yields. The better start of the 1929 crop with the higher nitrates, both in the soil and in the plant (Figs. 2 and 3) during the early period, was evident from crop measurements. The improved status of the smaller crop toward the end of the season of 1929 was reflected by relatively high nitrates in soil and plant, and 3.27% of total nitrogen in the harvested roots as compared with 3.16% in the larger crop from the single application. Alpha-amino nitrogen determinations did not show consistent differences (Fig. 3).

Until the results were charted, the low yields of 1929 were ascribed

to nitrogen losses from leaching by the heavy rains in September, but a similar dip in the curves for 1930 during a period of extremely low rainfall shows that the nitrate disappearances were from other causes, presumably absorption by the crop.

A single application of nitrogen proved as effective for cabbages and beets as did the more laborious method of fractional applications.

TOMATOES AND SPINACH

Murry's Early Wonder tomatoes were set late in May and the fruits picked as they ripened until late in August when all remaining fruits were harvested. A Savoy type of spinach planted following the tomato harvest was ready for cutting late in October. Data showing the nitrogen fertilization and yields for these two crops appear in Table 2. Tomato yields include both green and ripe fruits. In 1929, the tomato yields were in favor of the single application, 388.5 bushels as compared with 322.7 bushels from the side-dressings, but early defoliation from disease prevented normal yields. The comparison for similar treatments in the following year was 654.2 bushels vs. 635.8 bushels—yields that are fairly satisfactory but not significantly different. Early pickings before August 12 were substantially alike for both treatments in 1929, but in 1930 the single application produced 33 bushels more than did the fractional treatment.

Nitrate nitrogen data are available only for the top 7 inches of soil in 1929, but in 1930 the results represent a 14-inch layer (Fig. 4). The data for the two seasons are not strictly comparable, as experience for similar conditions has shown that the nitrate concentrations in the plow slice are greater than those in the second 7-inch layer unless influenced by heavy rainfall. It is evident from the graph that soil nitrates were more abundant in the surface soil under the crop that had the single application in 1929. This probably accounts for the better yield from that crop, although the accumulation in the plant juice was seldom greater than that in the leaves of the smaller crop during the period when samples were taken (Fig. 5). The changes in the alpha-amino nitrogen concentrations in the juice tended to parallel those for nitrate nitrogen.

The relationship between vegetation and fruit production in tomatoes is not constant, but of the two crops compared vegetation measurements were significantly greater from July 9 to 24 for the crop from a single application. Prior to that period and for the week that followed the differences in size were insignificant.

In 1930, the nitrate concentrations were greater for the single application at the first sampling date, but differences thereafter were

less than 5 p. p. m. of nitrogen, and the weights of harvested fruits were approximately equal for the two crops. The higher nitrates initiated by the single application apparently increased the first pickings by 33 bushels in 1930.

Good stands of spinach were obtained following tomatoes in both 1929 and 1930. For the first season the yields were 920 bushels and 1,420 bushels for the single and fractional treatments, respectively; in 1930 identical weights equivalent to 1,980 bushels were harvested on the two areas.

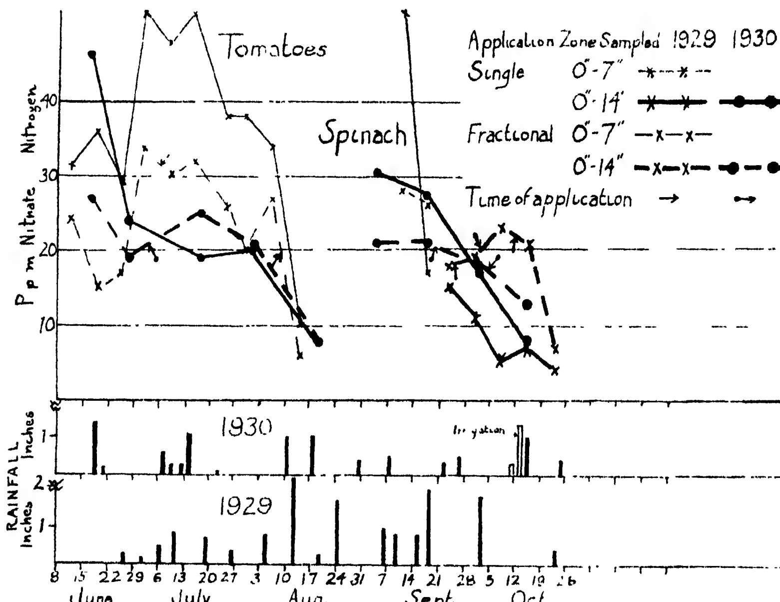

FIG. 4.—Nitrate nitrogen in the soil under tomatoes and spinach.

The fact that the fractional treatment produced the better yield in 1929 is of especial interest as it is contrary to the findings for crops discussed previously in this paper. The explanation may be seen in the graph of nitrate-nitrogen concentrations in the soil (Fig. 4). For the first two sampling dates, only determinations in the upper 7-inch layer are available, but thereafter the results represent a 14-inch layer. Frequent heavy rains falling soon after the initial fertilization removed the nitrates to such an extent that the side-dressings applied subsequently were unusually effective, maintaining a level of approximately 20 p. p. m. of nitrate nitrogen for 4 critical weeks, while the concentrations in the soil unsupported by side-dressings dropped steadily from 15 p. p. m. to less than 10 p. p. m. This condition is

reflected also in the results for nitrate nitrogen in the juice samples, but to a lesser extent (Fig. 5). Alpha-amino nitrogen was uniformly high in the larger crop, whereas there are three low points in the curve representing the plants of the depressed crop (Fig. 5). Plant measurements were always larger for the crop that had the side-dressings.

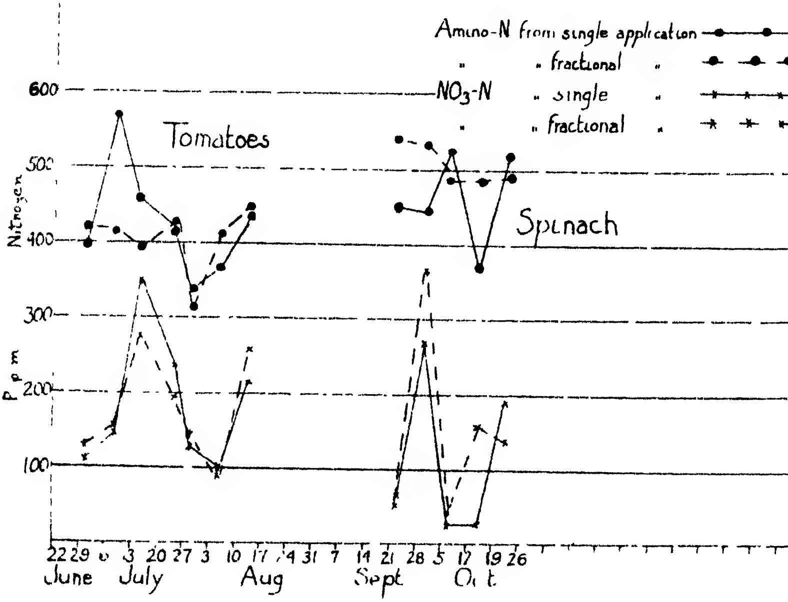

FIG. 5.—Nitrate and alpha-amino nitrogen in the juice from leaves of tomatoes and spinach, midribs excluded, 1929 crop.

The spinach in 1930 also received abundant soil nitrates following the large single application, and, without interference from leaching, this condition remained until the first of October after which the supplies from the two treatments were nearly equal, with only a small difference in favor of the side-dressings (Fig. 4). The yields were identical.

CELERY

Plants of Golden Plume celery were set in July after the removal of a crop of lettuce. At this time in the summer the soil is frequently too dry for the optimum starting of tender plants. To avoid increasing the concentration of soluble salts at this critical period, the recent custom has been to withhold the nitrogen and potash salts in the fertilizer mixture until the crop is well established. For the purpose of the experiment, this procedure was followed for the fractional

treatment. No nitrogen or potash were applied before the plants were set, but the entire quantity was used as side-dressings. The complete fertilizer mixture was harrowed in before the plants were set on the single-application area.

In the second season (1930), irrigation factilities were available and sufficient water was used to afford the plants a good start regardless of fertilizer applications. With these cultural methods in mind, it is interesting to note that in 1929, when irrigation was not available, the yields of trimmed celery were 115.8 cwt. for the single application and 150.6 cwt. for the fractional treatment. For the following year, the corresponding yields were 241.2 cwt. and 211.2 cwt., thus reversing the relationship. Crop measurements in 1929 show that the celery that received no nitrogen or potash at settling time made a much better start and continued to be significantly larger than the crop from a single application throughout most of the growth period.

Nitrate nitrogen in the upper 7 inches of soil reached a high level following the single application in 1929 and remained in greater abundance than under the better crop of celery from the fractional application, despite heavy rains (Fig. 6). After September 10, the data represent the upper 14-inch layer. In the leaves, however, there was a tendency toward the reverse relationship, for during the early part of the growth period, except at one sampling date, there were more nitrates in the crop growing on the soil with less nitrates (Fig. 7). This unusual condition is considered to be additional evidence of injury to the root systems of the tender plants from increasing the concentration of soluble salts by applying fertilizer to a dry soil. After September 3, the differences in the soil nitrates for the two crops were small. Alpha-amino nitrogen concentrations in the juice samples were very similar throughout the season, except for the first 2 weeks of the sampling period, when there was materially more in the faster-growing crop (Fig. 7).

No crop measurements were made for the celery set in irrigated soil in 1930, but the two crops appeared to grow equally well. Nitrate nitrogen accumulations in the upper 14 inches of soil were greater at the start from the larger application, but two successive side-dressings overcame this lead by August 19 and the two that followed provided the larger quantities of nitrates for the fractional treatment thereafter (Fig. 6). The yields were 14% greater following the single application.

GENERAL DISCUSSION

Observations for field experiments apply strictly only to the locality studied so that it may be of purely local importance that of the 12

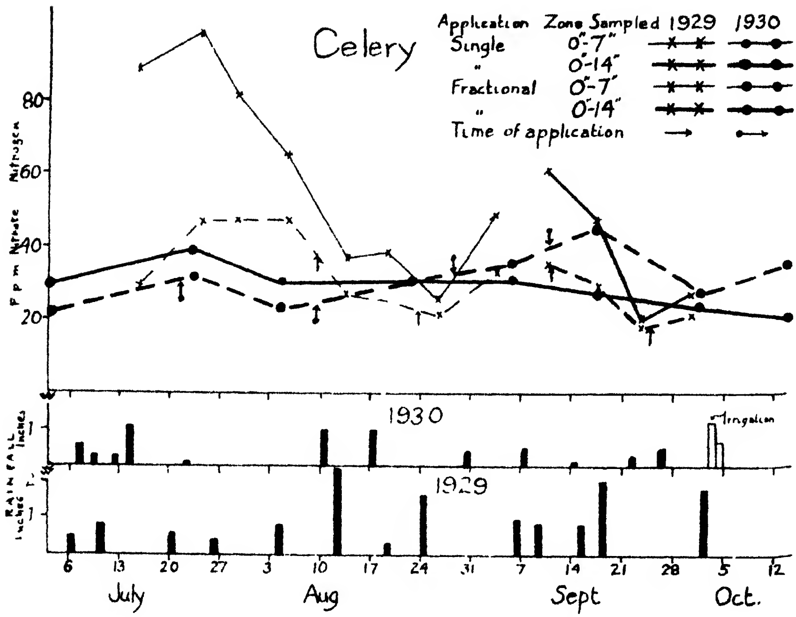

FIG. 6.—Nitrate nitrogen in soil under celery

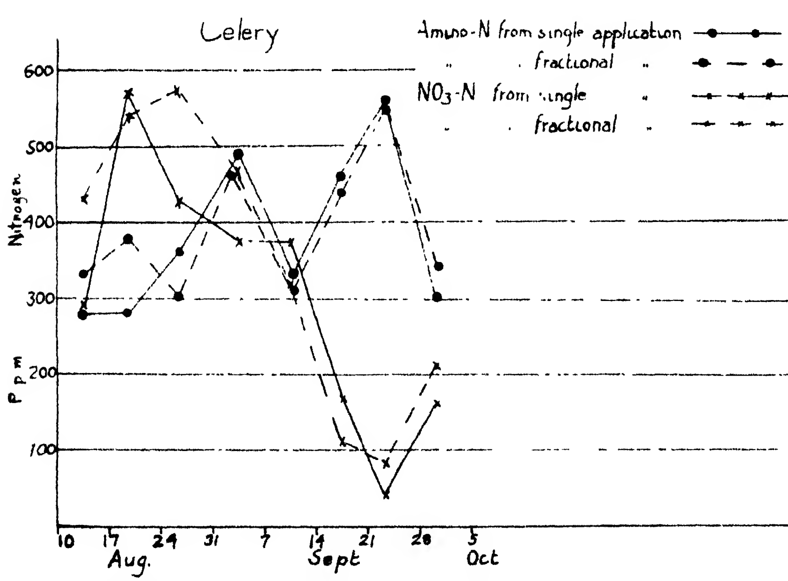

FIG. 7.—Nitrate and alpha-amino nitrogen in the juice from celery leaflets, midribs excluded, 1929 crop.

comparisons recorded in this work with vegetable crops, only 2 definitely favor fractional applications of soluble nitrogen as comcared with the less laborious and more common practice of a single application at planting time. Of greater general importance is the fact that in the two instances of benefit from the fractional method of fertilization the advantage was not because of the specific nature of the crop but was due to changes in the soil or weather, for in both instances a repetition of the experiment in the following year failed to confirm the findings of the first. Under different sequences of weather changes for this soil type, and more pronouncedly for soils that are more subject to leaching or fluctuation in the biological population, it is quite conceivable that the results of experiments similar to the ones here reported would be very different. The empiricism of such experiments will remain until interpretation is made upon the common ground of a more detailed knowledge of the factors that affect growth than is provided by dates and amounts of fertilizer applications and by yields.

It cannot be claimed that the measurements of the nitrogen fractions in soil and plant chosen for this study are sufficient or always pertinent for a satisfactory explanation of the yields recorded, but they are helpful. The periodic determination of soil nitrates, better than of any other nitrogen fraction, shows the fate of nitrogenous fertilizers. In general, when leaching rains did not interfere, this study has shown a tendency for the higher soil-nitrate concentrations from the relatively larger single applications of nitrogen at planting time to persist well into the growth period of the crop, and in certain instances to remain greater throughout the growing season than the accumulations from the successive small side-dressings of the fractional method of application More frequently, however, the curves showing the changes in the accumulations of nitrate nitrogen crossed at some time in the season, showing that the crops supplied with less nitrates during the seedling stage were supplied more liberally during the latter part of the growth period. Where leaching robbed the single-application treatment of the nitrates intended to last through the season, determinations of nitrate nitrogen in the soil disclosed the losses and measured the greater supplies of available nitrogen under the plants that received side-dressings subsequently, thus accounting for the larger yield from the fractional applications.

The quantities of nitrate nitrogen in the plant give assurance of the actual entry of nitrates from the soil and measure the accumulations that form reservoirs for current needs. The concentration in different parts of the plant vary (5), and the particular tissues chosen for this

work may not have been the best. The results are usually correlated positively with soil nitrates, but the actual concentration found represents the differential between the rate of metabolism and that of intake, so that following a period of rapid synthesis it is possible to find low nitrates in plants with sufficient nitrates about the roots. Such changes will not destroy the relationship between two crops that differ only in the rate of supply of nitrates, but will present a somewhat different picture from that provided by soil nitrates and add materially to a knowledge of the constantly changing situation.

A demonstration of the value of the determination of nitrates in blant juice is afforded by the results for the 1929 crop of celery, discussed previously. The apparent failure of tender plants to root in dry soil, where possibly critical osmotic conditions were accentuated by the application of soluble fertilizer salts, caused less accumulation of nitrates in the juice of the crop than in that of plants growing in a relatively low-nitrate soil.

Not as much can be said for the value of the alpha-amino nitrogen fraction. This is a measurement of a reserve for protein synthesis at a different stage in metabolism and is usually correlated positively with soil and plant nitrates, but the concentrations fluctuate widely and rapidly, and the determinations have added little of interest to the present study.

It is very probable that the measurement of other nitrogen fractions in soil and plant, or of the fractions here mentioned in different soil levels or plant tissues, would prove more valuable than those chosen. The object of this paper is the advocacy of some type of analysis to show the relative rates at which nitrogen is supplied to the plant by different methods of nitrogen fertilization, rather than basing judgment only upon dates and quantities of applications of an element, the available forms of which are known to be somewhat evanescent in the soil. A practical corollary is the use of periodic chemical determinations for the control of nutritional levels in the soil. Definite knowledge of the requirements of the plant at different growth stages is needed, but from the evidence gained in this study of vegetable crops a single application of nitrogen at planting time, normally sufficient to carry the plant to maturity, seems best for moderately heavy soils. This must be supplemented by side-dressings when heavy or long-continued rains cause serious leaching. The exception is for tender plants set in dry soil. The evidence and the conclusions of this study do not apply to light sandy soils that leach more readily than the type studied.

SUMMARY

The relative efficiency of single applications of nitrogen at planting time and of fractional applications furnishing an equal quantity of nitrogen during the growth of the crop were compared for field-grown onions, cabbages, tomatoes, beets, celery, and spinach, with respect to the accumulation of nitrates in a silty loam soil, nitrate and alpha-amino nitrogen in the juice of plant leaves, growth rates, and yields. The nitrogen was supplied largely by mixtures of nitrate of soda and sulfate of ammonia. Data for soil nitrates and crop yields were obtained for two consecutive years.

Grouping all of the experiments together, the single application produced significantly larger yields in three trials, approximately equal yields in seven, and inferior yields in two.

Usually the greater concentrations of soil nitrates initiated by the single application persisted well into the growth period of the crop, but these were ultimately exceeded by the accumulations from the successive side-dressings of the fractional treatment. This condition was reflected in the nitrate concentrations of the juice from plant leaves. The two outstanding deviations from these normal conditions were noted in the analyses of soil and plant in the two instances of better crop yields from the fractional applications. In one case, a crop of spinach was robbed of its supply of nitrogen by permanent leaching soon after the initial fertilization, and the losses were only replaced by the nitrogen reserved for side-dressing for the fractional treatment. The other instance demonstrated relatively low concentrations of nitrate nitrogen in tender celery plants transplanted into a dry, high-nitrate soil. This indicated root damage from critical concentrations of salts in the soil solution, enhanced by the addition of soluble fertilizer salts at planting time. Both nitrogen and potash salts were withheld from the fractional treatment until the crop was established, resulting in greater quantities of nitrate in the plant juice on three of the first four sampling dates, a more rapid growth rate, and a larger yield. Normal conditions were produced in the following year by irrigation before transplanting, and no advantage from the fractional method of fertilization resulted.

In so far as work for two seasons upon a single soil type justifies conclusions, it appears that for moderately heavy soils well supplied with moisture, sufficient nitrogen for these vegetable crops should be included in the fertilizer applied before planting, but that side-dressings should be used to replace abnormally great losses from leaching.

The periodic determination of nitrate nitrogen in the soil and in the

juice of plants is a valuable method of measuring the current supplies of available nitrogen, but the additional determination of alpha-amino nitrogen in plant juice was of little benefit in this study.

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EFFECT OF TILLAGE TREATMENTS ON SOIL NITROGEN AND CARBON[1]

M. C. SEWELL and P. L. GAINEY[2]

In wheat production throughout the hard winter wheat region of central Kansas timeliness of tillage has been one of the most important factors affecting acre yield. Experiments of the Kansas Agricultural Experiment Station extending over a 20-year period have shown that July plowing for the fall seeding of winter wheat has produced an average increase of 10 bushels per acre over September plowing. This increase has been shown to be due to greater supplies of nitrate nitrogen at seeding time, brought about by the control of weeds and decomposition of crop residues through early summer plowing (1, 2, 3, 4).[3]

The accumulation of nitrates can take place only at the expense of

[1]Contribution No. 204 from the Department of Agronomy and No. 139 from the Department of Bacteriology, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication July 27, 1931.

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[3]Reference by number is to "Literature Cited," p. 227.

TABLE 1.—*Nitrogen analyses, 1915–30, wheat seedbed preparation, continuous wheat, Manhattan, Kan.*

Plat No.	Tillage treatments, 1909–25	Percentage of nitrogen in 1915			Percentage of nitrogen in 1930		
		0–3 in.	4–7 in.	0–7 in.	0–3 in.	4–7 in.	0–7 in.
1	Disked at seeding time	0.164	0.171	—	0.164	0.162	—
2	Plowed Sept. 15, 3 in. deep	0.161	0.171	—	0.160	0.159	—
3	Double disked July 15; plowed Sept. 15, 7 in. deep	—	—	0.166	—	—	0.149
4	Double disked July 15; plowed Aug. 15, 7 in. deep	—	—	0.158	—	—	0.145
5	Plowed Sept. 15, 3 in. deep	0.157	0.160	—	0.156	0.151	—
6	Listed July 15; ridges worked down	—	—	0.156	—	—	0.140
7	Listed July 15; ridges split Aug. 15; worked down*	—	—	0.161	0.142	0.141	—
8	Plowed Sept. 15, 3 in. deep	0.157	0.159	—	0.148	0.151	—
9	Plowed July 15; 7 in. deep	—	—	0.152	—	—	0.140
10	Plowed Aug. 15; 7 in. deep	—	—	0.163	—	—	0.150
11	Plowed Sept. 15; 3 in. deep	0.153	0.154	—	0.151	0.151	—
12	Plowed Aug. 15; 7 in. deep, not worked until Sept. 15.	—	—	0.149	—	—	0.138
13	Plowed Sept. 15; 7 in. deep†	—	—	0.142	—	—	0.135
14	Plowed Sept. 15; 3 in. deep	0.143	0.147	—	0.136	0.138	—
15	Plowed July 15; 3 in. deep	0.136	0.145	—	0.125	0.129	—

*Plowed July 15, 3 in. deep since 1925. †Plowed July 15, 7 in. deep since 1925.

TABLE 2.—*Nitrogen changes during a 15-year period, 1915–30, in comparison with average nitrate development at seeding time, continuous wheat culture, Manhattan, Kan.*

Plat No.	Tillage treatment, 1909–25	Loss of nitrogen, lbs. per acre*				Ave. nitrates seeding time, lbs. per acre	
		0–3 in.	4–7 in.	0–7 in.	Total	0–1 ft.†	0–3 ft.‡
1	Disked at seeding	0	107	—	107	43	75
2	Plowed Sept. 15; 3 in. deep	9	143	—	152	71	96
3	Double disked July 15; plowed Sept. 15; 7 in. deep	—	—	355	355	171	236
4	Double disked July 15; plowed Aug. 15; 7 in. deep	—	—	271	271	207	322
5	Plowed Sept. 15; 3 in. deep	9	107	—	116	54	86
6	Listed July 15; ridges worked down	—	—	334	334	182	268
7	Listed July 15; ridges split Aug. 15; worked down‖	—	—	396	396	236	311
8	Plowed Sept. 15; 3 in. deep	81	95	—	176	161	118
9	Plowed July 15; 7 in. deep	—	—	250	250	179	300
10	Plowed Aug. 15; 7 in. deep	—	—	271	271	136	193
11	Plowed Sept. 15; 3 in. deep	18	36	54	54	43	96
12	Plowed Aug. 15; 7 in. deep; not worked until Sept. 15	—	—	229	229	111	161
13	Plowed Sept. 15; 7 in. deep§	—	—	146	146	43	75
14	Plowed Sept. 15; 3 in. deep	63	107	—	170	32	75
15	Plowed July 15; 3 in. deep	98	189	—	287	125	215

*Weight of soil per acre foot, 3,577,147 pounds. †1910–22. ‡1910–19
‖Plowed July 15, 3 in. deep since 1925. §Plowed July 15, 7 in. deep since 1925

the soil's supply of nitrogen. Hence, it is to be expected that soil plowed every year in the early summer for continuous wheat production will, as time goes on, contain less nitrogen than fields plowed late in which lower quantities of nitrates are developed.

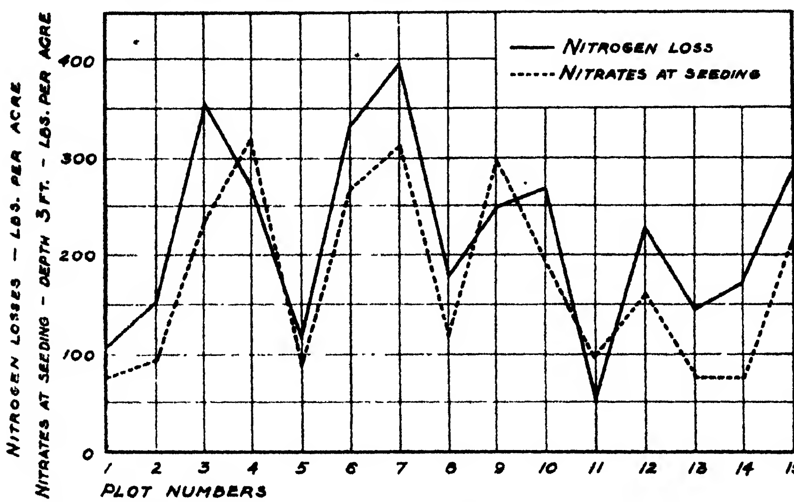

FIG. 1.—Relationship between nitrates at seeding time and nitrogen losses.

The wheat seedbed preparation project begun in 1910 at Manhattan comprised 30 tenth acre plats. Fifteen of these plats have been cultivated at various dates and depths and planted each year to wheat. The other fifteen plats have been rotated in blocks of five to corn, oats, and wheat, with several dates and depths of plowing for wheat. Nitrogen and carbon analyses were made in 1915 and again in 1930, affording comparisons regarding the changes that have taken place in the soil's supply of these elements.

RESULTS OF EXPERIMENTS

The data for nitrogen are presented in Tables 1 and 2 and are shown graphically in Fig. 1.

A study of these data substantiates the simple reasoning that nitrification can only take place at the expense of the soil's supply of total nitrogen. The greatest losses of nitrogen have occurred with the tillage treatments that have caused the largest amount of nitrate development. The relationship between nitrogen lost and nitrate development in the first foot when calculated statistically is represented by a correlation coefficient of 0.856 ± 0.0466.

In the rotation part of the wheat seedbed project, where wheat has been rotated with corn and oats, the losses of nitrogen have been

greater than under continuous wheat culture and the losses are more closely correlated with depth of plowing for wheat than with date of plowing. In this rotation, all of the land is fall plowed 7 inches deep

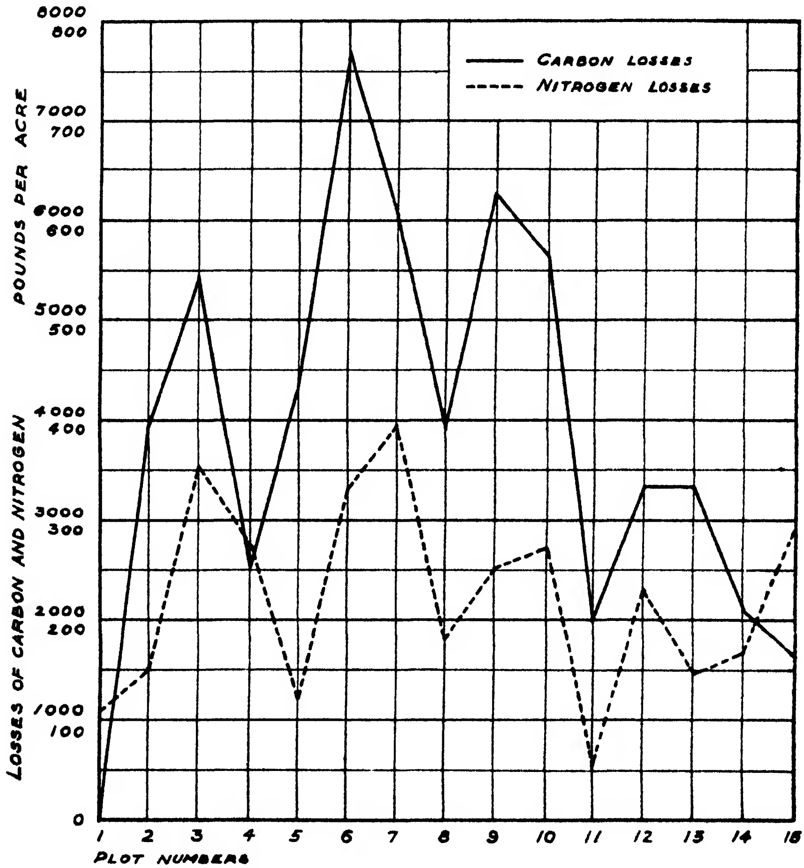

FIG. 2.—Relationship between nitrogen losses and carbon losses

for corn regardless of the depth of plowing for wheat. Oats have been planted on disked corn stubble land. The average nitrogen losses as related to tillage treatments for wheat are given in Table 3.

Here, also, there is shown to exist a relation between nitrogen losses and the amount of nitrate nitrogen present in the soil at seeding time, the correlation coefficient being .613 ± .188.

The carbon analyses first made in 1915, five years after the project was begun, show a wide variation in the organic matter content of the soil, decreasing in quantity from plat 1 at the south to plat 15 at the north. The range is from 2.06 to 1.53%.

TABLE 3.—*Average losses of nitrogen per acre in wheat seedbed rotation.*

Tillage treatment for wheat	Losses of nitrogen, lbs. per acre	Nitrates at seeding, lbs. per acre, 11-year average, 3 ft.
Plowed July 15, 12 in	500	247
Plowed July 15, 7 in	576	215
Plowed July 15, 3 in	391	204
Plowed Aug. 15, 7 in	444	150
Plowed Sept. 15, 3 in	378	86

The soil samples taken in 1930 were analyzed for carbon and the loss of carbon was calculated for the 15-year period which had elapsed. The data are given in Table 4 and are presented graphically in Fig. 2.

The carbon losses are on the whole greater for the early than for the late tillage treatments. Since the carbon content at the beginning of the period of observation increased toward plat 1, one might expect the carbon losses to be proportionately greater than where the original carbon content was lower. There is some indication that such has been true, but in certain instances, notably plat 1, this factor has been completely overshadowed by the effect of the treatment.

Correlation of carbon losses with total nitrogen losses is not close as is the case between nitrogen loss and nitrate development, yet with minor exceptions the trends are identical.

SIGNIFICANCE OF NITROGEN SUPPLY

Results at the Kansas Experiment Station have shown that the acre yield of wheat is proportional to the supply of available nitrogen at seeding time. Early summer tillage has increased the acre yield as much as 10 bushels because of its effect on the nitrate development. However, one must not lose sight of the fact, very clearly indicated by these data, that parallel with increased nitrate production and consequent increased yields as a result of early summer tillage, there is also an increased depletion of the soil's store of nitrogen. These data should not be taken to indicate that early summer tillage is not advisable, but rather to emphasize the importance of maintaining a reserve nitrogen supply in order to obtain the maximum benefits from early summer tillage.

Where the average annual precipitation exceeds approximately 21 inches in the Kansas winter wheat region, the reserve supply of nitrogen can probably be maintained by growing legumes, particularly sweet clover, upon a portion of the wheat acreage. This would include the wheat region as far west as Russell County in the central portion of the state and somewhat farther west in the northern tier of counties.

TABLE 4.—*Carbon changes during a 15-year period, 1915–30, continuous wheat culture, Manhattan, Kan.*

Plat No.	Tillage treatment, 1909–25	Percentage of carbon in 1915			Percentage of carbon in 1930			Gain or loss of carbon, lbs. per acre‡		
		0–3 in.	4–7 in.	0–7 in.	0–3 in.	4–7 in.	0–7 in.	0–3 in.	4–7 in.	0–7 in.
1	Disked at seeding time	2.00	1.99	—	2.15	1.88	—	+1,476	—1,311	+165
2	Plowed Sept. 15, 3 in	2.04	2.05	—	1.93	1.80	—	—983	—2,980	—3,964
3	Disked July 15; plowed Sept. 15, 7 in	—	—	2.06	—	—	1.80	—	—	—5,425
4	Disked July 15; plowed Aug. 15, 7 in	—	—	1.94	—	—	1.82	—	—	—2,504
5	Plowed Sept. 15, 3 in	1.87	1.94	—	1.67	1.73	—	—1,968	—2,504	—4,292
6	Listed July 15, ridges worked down	—	—	1.94	—	—	1.57	—	—	—7,720
7	Listed July 15 ridges split Aug. 15; worked down*	—	—	1.95	1.62	1.57	—	—	—	—6,025
8	Plowed Sept. 15, 3 in. deep	1.91	1.97	—	1.66	1.85	—	—2,460	—1,431	—3,891
9	Plowed July 15, 7 in. deep	—	—	1.98	—	—	1.68	—	—	—6,260
10	Plowed Aug. 15, 7 in. deep	—	—	1.98	—	—	1.71	—	—	—5,634
11	Plowed Sept. 15, 3 in. deep	1.84	1.95	—	1.76	1.85	—	—787	—1,192	—1,979
12	Plowed Aug. 15; not worked until Sept. 15	—	—	1.77	—	—	1.61	—	—	—3,338
13	Plowed Sept. 15, 7 in. deep†	—	—	1.72	—	—	1.56	—	—	—3,338
14	Plowed Sept. 15, 3 in. deep	1.73	1.73	—	1.53	1.64	—	—1,968	—1,073	—2,041
15	Plowed July 15, 3 in. deep	1.53	1.58	—	1.51	1.46	—	—197	—1,430	—1,627

*Plowed July 15, 3 in. deep since 1925.
†Plowed July 15, 7 in. deep since 1925.
‡Acre foot of soil weight 3,577,147 pounds.

Nitrogen fertilizers will increase acre yields considerably in the eastern part of the wheat region and could be used when prices of wheat justify their use. In the western part of the wheat region summer fallow should theoretically increase the nitrogen reserve through a greater free fixation of nitrogen (5).

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THE NITROGEN OUTLOOK[1]

JACOB G. LIPMAN[2]

Nitrogen fertilizers are now a common commodity in the world's markets. In these sodium nitrate and by-product sulfate of ammonia held undisputed sway for more than a half a century. How this supremacy was challenged and overcome is by this time an old story. Population pressure and the rising tide of competition from North and South America, from Australia, and from various tropical lands forced Western Europe to revise its agricultural policies. Intensification of production, higher yields per acre, lower unit costs, and the transition to secondary types of farming were the measures whereby older agricultural regions sought to offset the gains made by mechanized farming of fertile plains and swelling exports of sugars and fats from regions where the sun works longer and where human labor is cheap.

The early years of the present century showed the way to the technical fixation of atmospheric nitrogen on a large scale. Cyanamide and calcium nitrate made their entry into the fertilizer markets. Then came the stimulus of a world-wide conflict and of an insistent demand for explosives. Synthetic ammonia showed itself

[1]Contribution from the Department of Soil Chemistry and Bacteriology, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Also presented at the Pennsylvania Soil Fertility Conference, State College, Pa., June, 1931. Received for publication July 31, 1931.

[2]Director.

TABLE 1.—*World production of inorganic nitrogen in net tons of nitrogen per year.**

Source of production process	1909	1913	1917	1924–25	1928–29	1929–30
By-product ammonia	233,200	377,300	400,400	325,700†	427,000†	442,300†
Calcium nitrate	330,000	429,000	431,200	367,500	490,000	464,000
Air fixation:						
Arc process	3,300	19,800	33,000	25,000	136,000‡	130,500‡
Cyanamide process	2,750	66,000	220,000	115,000	210,000	263,600
Ammonia process	0	7,700	121,000	255,000	485,000	455,000
Other forms	—	—	—	66,100§	365,000§	423,000§
Total	569,250	899,800	1,205,000	1,154,300	2,113,000	2,178,400

*U. S. D. A. Circ. 129, 1931. Ann. Rpt. British Sulphate of Ammonia Federation, 1928–29 and 1929–30.
†Includes other forms of by-product nitrogen
‡Only partly by arc process.
§Most of it derived from ammonia.

able to make inroads into the trade already established for cyanamide and synthetic calcium nitrate. The rapid growth in the manufacture of synthetic ammonia is indicated in Table 1 compiled from data given by Howard and in the ninth and tenth annual reports of the British Sulphate of Ammonia Federation, Limited.

It is pointed out by Daugherty (1)[3] that "the German dye trust, the Ruhr by-product ammonia cartel, the cyanamide producers, the Silesian by-product ammonia cartel, and the gas plant cartel have a capacity of 1,164,500 tons, of which 1,062,500 metric tons is synthetic and the other 102,000 tons by-product." Elsewhere in the same bulletin he states, "Figures of production of fixed nitrogen by the German dye trust's giant synthetic (Haber-Bosch) plants at Merseburg and Oppau, indicate the development of nitrogen production. These two plants account for 65% of total German production, the other 35% originating in the calcium-cyanamide plants and the coke and gas plants. The Merseburg and Oppau plants produced 350,000 metric tons of contained nitrogen in 1925, 450,000 tons in 1926, 650,000 tons in 1928, and 550,000 tons in 1929."

The production of nitrogen fertilizers in France shows striking progress. In 1927 it was equivalent to 51,000 tons of nitrogen, in 1928 it was 65,000 tons, and in 1929 an equivalent of 79,000 tons. Despite this it was still necessary to import an equivalent of 100,000 tons of nitrogen, largely because of the increase of consumption from 125,000 tons in 1927 to 175,000 tons in 1929. Plants recently completed and others nearing completion will increase substantially the domestic output of fixed nitrogen (2).

The consumption of nitrogen fertilizers in the United States represents an equivalent of almost 400,000 tons of nitrogen. More than half of this is imported from Chile and Europe. As in other industrial countries there has been, in recent years, a notable expansion in the production of synthetic nitrogen compounds in the United States. It is estimated by Burdick (3) that by 1932 our production capacity will approximate 535,000 tons of nitrogen. This will consist of 180,000 tons of nitrogen in by-product ammonia, 300,000 tons in synthetic ammonia, and 35,000 in organic by-product materials. In other words, when the present construction is completed we shall be supplying more than half of our domestic production from synthetic sources.

Without going any farther afield we may note that the production of fixed nitrogen has been mounting in other countries. Not only Western Europe, but such countries as Russia and Japan have joined the procession. There is feverish activity in the building of nitrogen

[3]Reference by number is to "Literature Cited," p. 237.

TABLE 2.—*Location of and processes used by the nitrogen-fixation plants of the world at the end of 1929.*

(Capacity in net tons nitrogen per acre)

Country	Number of plants using the processes indicated and the net tons produced by them						Total capacity
	Arc		Cyanamide		Direct synthetic		
	Number	Capacity	Number	Capacity	Number	Capacity	
Belgium	—	—	—	—	5	106,500	106,500
Canada	—	—	1	80,000	1	2,500	82,500
Czechoslovakia	—	—	1	6,000	2	12,500	18,500
England	—	—	—	—	2	175,000	175,000
France	2	1,250	8	53,000	18	114,050	168,300
Germany	1	4,500	5	114,000	8	820,000	938,500
Italy	—	—	5	21,900	9	58,000	79,900
Japan	—	—	10	63,600	5	55,000	118,600
Netherlands	—	—	—	—	3	77,000	77,000
Norway	2	30,000	1	15,000	2	55,000	100,000
Poland	—	—	2	40,000	5	35,000	·75,000
Russia	—	—	—	—	1	7,000	7,000
Rumania	—	—	1	5,000	—	—	5,000
Spain	—	—	—	—	3	8,500	8,500
Sweden	—	—	2	6,000	1	2,000	8,000
Switzerland	—	—	2	5,000	1	7,000	12,000
United States	—	—	1	40,000	8	115,600	195,600
Yogoslavia	—	—	2	14,000	1	14,000	28,000
Total	5	35,750	41	463,500	75	1,704,650	2,203,900

fixation plants despite the world-wide agricultural and industrial depression. It is evidently anticipated that world agriculture is facing far-reaching changes and that these will involve, among other things, intensified fertilization and greatly increased yields per acre of proteins, carbohydrates, and fats.

The distribution in the production capacity of fixed nitrogen, as indicated in Table 2, is suggestive of further changes that are to occur in the near future. There is practically no limit to the amount of nitrogen that may be fixed for agricultural and industrial uses. It is conceivable that within 10 years there may be a world production capacity equivalent to 5,000,000 or even 10,000,000 tons of fixed nitrogen. In the long run, 70 to 90% of fixed and by-product nitrogen must be absorbed in agriculture, even though the dream of the organic chemist to produce synthetic proteins may be realized. The nitrogen fixation industry must look to agriculture for its major market. For this very valid reason, it must survey the present and look into the future. It must deal with trends in human and animal populations, with land utilization policies, with dietaries and standards of living, and with things political and social, as well as with problems purely industrial and economic, if it is not to lose its way in the tangle of rivalries and cooperation through which no man can see clearly.

NITROGEN AS A FOOD FACTOR

When we consider the minimum protein requirements of man and domestic animals we arrive at some very impressive figures. Assuming for the human adult a daily intake of 100 grams of protein and basing our calculations of the protein requirements of domestic animals on the Morrison feeding standards, we are able to obtain a fairly adequate understanding of the place of nitrogen in the feeding of human and animal populations. But before we consider the data which follow we should bear in mind that there is a very intimate relation between the land needs and food habits of any people.

It was shown by Pearl (4) that plant protein, directly used, contributed only 45% of the protein requirements of the population of the United States. The balance was derived from meats, poultry, eggs, dairy products, and fish. But in the conversion of plant into animal proteins there is a terrific shrinkage in the ability of the land to support a teeming population. Where a vegetarian will survive on 1 acre, a carnivorous human will require 8 to 10 acres. Need we say more of the hidden and known facts in the history of mankind as we think of nitrogen and protein as a part of the human currents that arose in the mountains and lost themselves in the sands of the desert?

The "standing room only" sign was hung out many a time in many places and human locusts took flight. Was it the lust for plunder or the gnawing pains of hunger that drove Attila the Hun and others like him to the fertile plains of great rivers?

The "standing room only" sign has been hung out in China and in India and there are other places where now, or soon, this sign must be hung out. Given sufficiently high intelligence and ideals, populations will find their proper birth and death rate levels. But for the time being, there is before us a disquieting pattern of land, people, unemployment, hunger, ignorance, appeal to passions, the threat of war, nationalism and internationalism gone mad, and somewhere nitrogen fits into this pattern. Let us consider a few data on population and nitrogen consumption (Table 3).

TABLE 3.—*World population and nitrogen consumption.*

Year	Population	Nitrogen consumption from plant sources in short tons
1900	1,500,000,000*	4,390,000
1910	1,523,000,000*	4,460,000
1920	1,700,000,000*	4,970,000
1930	2,000,000,000	5,850,000

*Interpolated values.

With the daily protein intake calculated as 100 grams, the world population will require a yearly supply of less than 6,000,000 tons of nitrogen when subsisting on a vegetable diet. But when we consider the livestock population and its nitrogen needs, we come to a problem of a different order of magnitude. A glance at Table 4 will serve our purpose.

TABLE 4.—*World livestock population and its nitrogen needs*

	Cattle	Sheep	Swine	Horses and mules
	Yearly Average, 1909–13			
Population	561,600,000	692,200,000	264,236,000	129,900,000
N consumed*	35,375,000	7,955,000	7,250,000	8,967,500
	Yearly Average, 1921–25			
Population	646,700,000	647,100,000	266,424,000	117,200,000
N consumed*	40,800,000	7,445,000	7,340,000	8,095,000
Total Consumption of Nitrogen from Plant Sources by Livestock in Short Tons				
1909–13	59,547,500			
1921–25	63,690,000			

*Short tons.

We note with interest that domestic animals use at least 10 times as much protein as is required by the human population. We observe, likewise, that domestic cattle consume by far the largest proportion of the protein fed to all of the domestic animals. The animal population of the world is still increasing as is also their protein consumption, both relatively and absolutely.. It would be no exaggeration to say that with the food that they eat and with the part of it that they waste, there is a gross requirement of perhaps 100,000,000 tons of nitrogen for the subsistence of the domestic animals of the inhabited globe.

Since we are on the subject, we might consider the application of the facts noted above to the conditions in the United States. There are given in Table 5 data concerning our livestock population and its nitrogen requirements.

TABLE 5.—*The livestock population of the United States and its nitrogen requirements.*

	Cattle	Sheep	Swine	Horses and mules	Poultry
			1900		
Population....	67,720,000	61,504,000	62,868,000	21,532,000	250,624,000
N consumed*.	4,265,000	707,500	1,729,000	1,472,500	180,450
			1910		
Population ...	61,803,000	52,448,000	58,186,000	24,043,000	295,880,000
N consumed*.	3,932,500	603,000	1,600,000	1,660,000	213,050
			1920		
Population....	66,639,000	35,034,000	59,346,000	25,242,000	372,825,000
N consumed*.	4,217,000	402,850	1,632,000	1,740,000	268,400
			1930		
Population. .	57,968,000	48,913,000	52,600,000	18,719,000	492,500,000
N consumed*.	3,722,500	562,500	1,446,000	1,290,000	354,600

*Short tons.

Space will not permit the discussion of several interesting relations brought out in this table. It will serve our present purpose if we note that our changing dietaries and the mechanization of our farms have been an influence toward decreasing our livestock population, and toward increasing our poultry population. This change may be interpreted in terms of nitrogen consumption and an attempt at such interpretation is made in Table 6.

By way of comment on the data given in Table 6, it will suffice to mention that despite our growing population there has been a decreased consumption of nitrogen by the human and animal populations taken together. The shrinkage has been a notable one. On the other hand, the period 1900–30 witnessed a marked increase in the consumption of nitrogen from plant sources by the human population.

TABLE 6.—*Nitrogen consumption by the human and animal populations of the United States.*

Year	Human population	Total consumption of N from plant sources by humans in short tons	Total consumption of N from plant sources by livestock in short tons	Total N consumption, human and livestock, from plant sources
1900	76,000,000	222,300	8,354,450	8,576,750
1910	92,000,000	270,000	8,008,550	8,278,550
1920	105,700,000	307,370	8,260,250	8,567,620
1930	122,800,000	358,870	7,375,600	7,734,470

The information already given on our nitrogen requirements in human and animal foods may serve, if nothing more, as a check on the nitrogen requirements of our crops.

In Table 7 an attempt has been made to show the nature and extent of the losses and gains of nitrogen. The figures given are broad estimates at best. They should serve, nevertheless, in giving us a fairly satisfactory conception of the significance of the nitrogen factor in our land and crop economics.

It is indicated in Table 7 that the nitrogen removed in harvested crops and pasture grasses represents a minimum of 8,000,000 tons. If anything, these estimates are conservative. In addition, we must reckon with a loss of at least 900,000 tons of nitrogen brought about be leaching and of another 500,000 tons attributable to erosion. Figures given by Bennett (5) would indicate a substantially greater loss of nitrogen on account of erosion. All told, therefore, we may assume a total loss of nitrogen from our crop lands and pastures equivalent to 7,400,000 tons. As an offset against this, there is the gain of about 3,000,000 tons of nitrogen due to symbiotic and non-symbiotic fixation, a gain of 1,300,000 tons to be credited to atmospheric precipitation, and a further gain of approximately 400,000 tons of nitrogen contributed by inorganic and organic commercial fertilizers. The total gains, therefore, will be equivalent to 4,700,000 tons. This will leave a net loss of 2,700,000 tons.

It is scarcely necessary to point out that the forces which make for accumulation of nitrogen, on the one hand, and for its decrease, on the other, may be fairly well balanced in some soils. Generally speaking, there is a definite tendency toward an accumulation of nitrogen under a permanent cover, such as we find in our forests and permanent pastures. On the other hand, the land which is used for the growing of cultivated crops tends to suffer a progressive shrinkage in its nitrogen capital. In humid areas, drainage is the major source of loss. In dry farming areas, on the other hand, the rapid decomposi-

TABLE 7.—*The nitrogen balance sheet of the United States.*

Region	Total acreage of harvested crops for 1930	Losses in tons				Gains in tons		
		N removed in harvested crops*	N removed in pasturage*	N removed by drainage	N removed by erosion*	N gains by fixation*	N gains by rainfall	N gains in fertilizer*
North humid	144,817,000	—	—	579,268 (8 lbs. per acre)	—	—	579,268 (8 lbs. per acre)	—
South humid	58,051,000	—	—	290,255 (10 lbs. per acre)	—	—	348,306 (12 lbs. per acre)	—
Sub-humid	128,953,000	—	—	None	—	—	322,382 (5 lbs. per acre)	—
Semi-arid	22,788,000	—	—	None	—	—	11,394 (1 lb. per acre)	—
North Pacific	6,644,000	—	—	26,576 (8 lbs. per acre)	—	—	26,576 (8 lbs. per acre)	—
South Pacific	5,252,000	—	—	13,130 (5 lbs. per acre)	—	—	13,130 (5 lbs. per acre)	—
Total U. S.	366,505,000	5,500,000	1,500,000	900,000	500,000	3,000,000	1,300,000	400,000
Total losses and gains	—	8,400,000				4,700,000		

*Not calculated by regions.

tion of organic matter and the escape of elementary nitrogen may be a factor of significance. Furthermore, over-grazing may lead to a decrease in the nitrogen content of the soil even though losses from leaching and the rapid decomposition of the soil organic matter may not be serious.

In dealing with the nitrogen factor, we are brought face to face with the outstanding problem of land utilization. All things considered, we have not used our land wisely. Much land originally in forest should not have been cleared. Vast areas of range land should have been allowed to remain as they were. We have failed to establish and maintain land utilization policies in keeping with the fundamental facts of economics. After all, there is no excuse for hauling vast quantities of crop products for hundreds and thousands of miles if these same crops could be economically produced nearer to the centers of consumption. We have not fully reckoned with the climatic factor in its relation to the conservation and building of soil fertility. Neither have we definitely planned to establish cropping systems best calculated to produce economic returns for any given soil type.

The constant shifting of economic forces, the concentration of our population in growing cities, the absolute as well as the relative losses in the number of people on our farms, the new alignments in manufacture and merchandising, alignments international as well as national in their scope, call at this time for a serious review of our agricultural situation from the point of view of land utilization.

We have come to the point of intensified production. The facts already noted, taken together with the expanding supply of chemical fertilizers, are suggestive of new procedures in our farming. Too much emphasis cannot be laid on the need of sifting out various areas of land to be put again under forest or grass cover. Not being in themselves profitable, they are only a menace to the welfare of those who are trying to use profitably land which is legitimately agricultural. Too much emphasis cannot be laid on the desirability of concentrating our efforts on land that will give economic returns. Such concentration of effort must of necessity involve higher yields per acre and, by the same token, greater net returns per unit of cultivated area. And here is where the nitrogen factor stands out in bold relief. Fixed nitrogen is cheap enough and abundant enough to justify its use as an aid toward a more prosperous agriculture. Since, as has already been noted, there is practically no limit to the quantity of fixed nitrogen that may be produced for agricultural uses, we should very seriously consider national and international inquiries in the

domain of soil and plant science as a first step toward building more rational crop production programs.

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MANGANESE CONTENT OF CERTAIN CONNECTICUT SOILS AND ITS RELATION TO THE GROWTH OF TOBACCO[1]

H. G. M. JACOBSON AND T. R. SWANBACK[2]

In a preliminary report (6),[3] the authors called attention to certain identical symptoms exhibited by tobacco when grown in solutions containing considerable manganese and on highly acid soils with an appreciable soluble manganese content. During the past 2 years the subject has been more fully investigated along the following lines: (a) Verification of definite manganese toxicity symptoms with tobacco; (b) analyses for manganese of soil and plant material, under various fertilizer treatments; (c) the effect of different increments of lime on the manganese (active) content of soil and plant material; (d) the active manganese content of 22 Connecticut soils before and after liming; (e) total and active manganese in 33 Connecticut soils from three sections of the state; (f) manganese content of leachates from greenhouse and lysimeter soils; and (g) distribution of manganese in the tobacco plant.

HISTORICAL REVIEW

Elwell (3), Godden and Guinmett (5), Johnson (7), Kelly (8), Lindsey (9), and others have found that plants become chlorotic when grown in a soil containing a high amount of soluble manganese. Deatrick (2), working with water cultures, observed that when the

[1]Joint contribution from the Department of Soils, New Haven, and the Tobacco Substation, Windsor, of the Connecticut Agricultural Experiment Station, New Haven, Conn. Received for publication August 8, 1931.

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[3]Reference by number is to "Literature Cited," p. 245.

concentration of manganese was greater than 10 p. p. m. toxicity occurred.

Carr and Brewer (1), Funchess (4), McHargue (10), Mann (11), Schollenberger and Dreibelbis (12), and Skinner and Sullivan (13) found that soluble manganese in soils was decreased by reducing the acidity.

Manganese was determined by the periodate method as described by Willard and Greathouse (14).

VERIFICATION OF DEFINITE MANGANESE TOXICITY SYMPTOMS IN TOBACCO

In order to determine whether manganese was causing a peculiar abnormal condition in the foliage of tobacco plants, a soil of low active manganese (soluble in N/2 acetic acid) content was placed in two greenhouse flats and set to tobacco plants. One of the flats was watered with tap water, while the other was watered with a weak solution of manganese sulfate. The resulting growth was fairly normal in the manganese sulfate watered flat and showed only slight traces of the unusual symptoms previously noted on plants in the greenhouse. Analyses of the soil and plant material of both flats were made. The soil and the plant material of the manganese-treated flat showed considerable amounts of manganese A second crop of tobacco was set in the same flats and the treatments continued. The resulting plant growth in the manganese flat showed identical abnormalities noted in plants in the greenhouse. The analyses of the soil and of the plant material from the two flats are set forth in Table 1.

TABLE 1.—*Manganese content of soil and tobacco plants from greenhouse flats.*

	1928		1929	
	Plant material %	Soil active Mn %	Plant material %	Soil active Mn %
Mn-treated flat	0.453	0.028	1.429	0.091
Untreated flat	0.056	Trace	0.041	Trace

A comparison of the manganese content of the soil and plant material for the 2 years (Table 1) suggested very strongly that tobacco was a luxury feeder on active manganese.

Verification of manganese toxicity symptoms was also attempted by the use of water, sand, and field cultures. For manganese studies in water cultures a modification of Crone's nutrient solution was

selected. It had the following partial-volume molecular concentration:

Tricalcium phosphate	0.0022
Ferric phosphate	0.0019
Magnesium sulfate	0.0114
Calcium sulfate	0.0052
Potassium chloride	0.0075
Ammonium nitrate	0.0278

The nutrient solution was poured in 1-quart mason jars in sufficient quantity to make up quadruplicate treatments of 0, 1, 3, 6, 9, and 12 p. p. m. of $MnSO_4$.

One tobacco plant was fastened in a cork stopper and set in each jar. The solutions were not changed during the period of growth, but distilled water was added to keep the volumes constant. Care was also taken to keep the light out of the solutions. In jars where no manganous sulfate was added plants made a fair growth, but plants grown in manganese-treated cultures showed injury after the first week. No yield data were taken but observations on conditions of plants after remaining 65 days in the cultures were as follows:

No treatment	Healthy growth.
1 p.p.m. $MnSO_4$	Stunted growth, brown top, upper leaves crinkled.
3 p.p.m. $MnSO_4$	Stunted growth, brown top, 1 plant died.
6 p.p.m. $MnSO_4$	Stunted growth, brown top, 2 plants died.
9 p.p.m. $MnSO_4$	Stunted growth, brown top, 2 plants died.
12 p.p.m. $MnSO_4$	Stunted growth, brown top, 3 plants died.

Since as low a concentration as 1 p. p. m. of $MnSO_4$ in the nutrient solution resulted in stunted growth of the tobacco plant, it is apparent that a considerably lower concentration should be available at any one time, provided that manganese will stimulate growth at all.

TABLE 2.—*Dry weights of tobacco plants grown in sand cultures.*

Common sand		Pure silica sand	
Treatments	Rel. weights	Treatments	Rel. weights
Check, no $MnSO_4$	100	Check no $MnSO_4$	100
3 p.p.m. $MnSO_4$	77	1 p.p.m. $MnSO_4$	66
9 p.p.m. $MnSO_4$	78	2 p.p.m. $MnSO_4$	100
27 p.p.m. $MnSO_4$	100	4 p.p.m. $MnSO_4$	70
81 p.p.m. $MnSO_4$	85	8 p.p.m. $MnSO_4$	79
243 p.p.m. $MnSO_4$	60	50 p.p.m. $MnSO_4$	96
729 p.p.m. $MnSO_4$	51		

Using the same nutrient solution as mentioned above applied to common sand and to pure silica sand, normal growth was obtained

up to an application of about 80 p. p. m. of $MnSO_4$. The increments of $MnSO_4$ and relative yields are shown in Table 2.

A glance at Table 2 gives the evidence that the use of $MnSO_4$ in no instance resulted in a yield higher than the check. Observations during growth showed that the plants in the 80 p.p.m. concentration gradually grew out of the injury, while in the two highest concentrations plants continued to develop abnormal leaves. The first symptom of the injury was a yellowing of the top leaves. When the leaf was fully developed the yellowish color was minutely distributed in the interspaces of the finest ramifications of the leaf veins, the color being most pronounced toward the tip of the leaf. In later stages of growth the entire leaf took on a more yellow color, but the "pattern" remained the same. In still later stages some of the leaves crinkled and brown irregular spots were distributed over the leaf surface.

Field tests on three manganese compounds were made later at the Tobacco Substation at Windsor, Conn. Sulfate, carbonate, and sesquioxide, in addition to general tobacco fertilizer, were applied to a soil of sandy Merrimac loam on which tobacco was planted.

Results from this test showed that the sulfate applied at a rate of 1 pound to the acre gave an increase in yield of 87%. The sesquioxide and the carbonate needed to be supplied at a rate of 2 pounds to obtain similar results.

When the field test with manganous sulfate was repeated a second year, no increase in yield of tobacco was observed. On the other hand, an application of 486 pounds of manganous sulfate to the acre neither depressed the yield nor did it cause any injury to the tobacco plants.

ANALYSES FOR MANGANESE OF SOIL AND PLANT MATERIAL UNDER VARIOUS FERTILIZER TREATMENTS

It was noted that manganese toxicity symptoms did not appear on limed soils and also that the toxicity was more severe in some cases on the unlimed soil. This led to the belief that soil reaction may serve as an indicator of the supply of active manganese in a soil. As a preliminary investigation, two soils which showed pronounced manganese toxicity with tobacco and which had been treated with various fertilizer elements and lime, were set to tobacco. The resulting crop was analyzed for manganese content. The active manganese and the reaction of the soil were also determined. The results obtained are shown in Table 3.

It was quite evident (Table 3) that the soil reaction had a direct correlation with the amount of active manganese in the soil and in-

directly with the quantity taken up by the tobacco plant. Even a slight change in the reaction of the soil produced marked differences both in active manganese of the soil and also in the manganese intake by the plant. The PK treatment in the above soils resulted in a decrease of soil acidity, a lower active manganese content of the soils, and lower manganese content of the plants.

TABLE 3.—*Manganese content of soil and tobacco plants with reaction of the soil.*

Treatment	Soil No. 234			Soil No. 237		
	Active Mn in soil %	Mn in plant material %	pH of soil	Active Mn in soil %	Mn in plant material %	pH of soil
O	0.0120	0.5250	4.33	0.0034	0.647	3.98
P	0.0084	0.8750	3.95	0.0037	0.669	3.93
PK	0.0016	0.0388	4.80	0.0029	0.380	4.01
L	0.0011	Trace	6.40	0.0004	Trace	5.03
LP	0.0012	Trace	6.43	0.000[illegible]	Trace	5.96
LK	0.0008	Trace	6.65	[illegible]5	Trace	6.11
LPK	0.0010	Trace	7.11	0.0[illegible]02	Trace	6.62
LNPK	0.0010	Trace	6.98	0.0005	Trace	6.81

The severity of visible manganese toxicity in the plants was in direct proportion to the percentage of manganese found in the plant material.

Additional evidence on the effect of the reaction of the soil on the manganese content of tobacco plants has been noted at the Windsor Tobacco Substation. For a number of years tobacco has been analyzed for manganese content on numerous fertilizer plats whose reaction was also determined. The results correlated with those of Table 3.

EFFECT OF DIFFERENT INCREMENTS OF LIME ON THE MANGANESE (ACTIVE) CONTENT OF A SOIL AND PLANT MATERIAL

It was evident that liming a soil reduced the amount of active manganese present. In order to determine the effect of fractional amounts of lime upon active manganese, four 2-gallon jars were filled with a soil known to be high in active manganese. The jars of soil were treated as follows: No lime, one-half the lime requirement, equal to the lime requirement, and twice the lime requirement, according to the Jones acidity method. Tobacco plants were set in the jars and grown to maturity. After the tobacco was harvested the soil was analyzed for active manganese and the plants for total manganese. The following season tobacco plants were again set in the jars. The crop and soil were analyzed as in the previous season.

The reaction of the soil at the end of each season was determined electrometrically. The results of these analyses are set forth in Table 4.

TABLE 4.—*Effect of fractional lime applications on soil reaction, active manganese in soil, and manganese content of tobacco plant.*

Treatment	First season			Second season		
	pH	Active Mn in soil %	Mn in plant material %	pH	Active Mn in soil %	Mn in plant material %
No lime ..	3.91	0.0450	1.167	4.28	0.0128	0.550
½ L. R.* .	5.00	0.0021	0.059	5.03	0.0016	0.045
L. R .	5.57	Trace	0.000	5.73	0.0012	Trace
2X L. R.*	6.89	Trace	0.000	6.83	0.0019	Trace

*L. R = Lime requirement.

The fractional lime applications (Table 4) did not neutralize the soil to the degree that was expected; nevertheless, the effects on the active manganese in the soil and the manganese composition of the plants were in line with the results found in the previous investigation. Application of only one-half the lime requirement resulted in a marked decrease of active manganese in the soil and also in the percentage of manganese in the plant.

TABLE 5.—*Reactions and active magnanese content before and after liming.*

Soil No.	Unlimed		Limed	
	pH	Active Mn, p.p.m.	pH	Active Mn, p.p.m.
223	4.91	16.2	6.82	9.6
224	4.09	16.5	6.82	11.7
225	3.94	26.6	6.96	11.7
226	4.83	43.7	6.75	11.7
227	4.17	65.9	7.28	11.7
228	4.24	93.0	7.00	4.8
229	4.07	24.1	7.17	3.6
230	4.13	117.0	7.42	19.2
231	3.97	87.0	6.83	9.6
232	6.98	46.0	7.00	33.0
233	4.81	24.0	7.11	21.7
234	3.96	409.0	7.01	30.0
235	5.32	28.1	6.58	16.8
236	5.04	25.5	7.23	11.7
239	4.11	91.0	6.59	9.6
240	4.91	19.2	6.18	19.2
241	4.99	20.2	6.38	11.7
242	4.80	9.8	6.75	11.7
243	3.85	94.0	6.98	16.8
244	4.18	18.2	7.51	16.8
245	4.93	28.5	6.57	16.8
246	4.45	13.1	6.38	16.8
Average	4.28	59.8	6.75	14.8

ACTIVE MANGANESE CONTENT OF 22 CONNECTICUT SOILS BEFORE AND AFTER LIMING

Twenty-two Connecticut soils were analyzed for active manganese before and after liming. Soil reactions were also determined. The results are shown in Table 5.

Liming (Table 5) reduced the active manganese in all soils except three. An average of reactions and active manganese of all the soils shows rather conclusively that a decrease in acidity is accompanied by a decrease in amount of active manganese.

TOTAL AND ACTIVE MANGANESE IN 33 CONNECTICUT SOILS FROM THREE SECTIONS OF THE STATE

Eleven soils from each of three sections of Connecticut were analyzed for total and active manganese. The results are set forth in Table 6.

TABLE 6.—*Total and active manganese in certain Connecticut soils.*

Western Highland			Central Valley			Eastern Highland		
Soil No.	Active Mn, p.p.m.	Total Mn, p.p.m.	Soil No.	Active Mn, p.p.m.	Total Mn, p.p.m.	Soil No.	Active Mn, p.p.m.	Total Mn, p.p.m.
225	26.6	387.5	223	16.2	350.0	228	93.0	325.0
229	24.1	537.5	224	16.5	362.5	237	91.0	287.5
230	67.5	400.0	244	18.2	300.0	311	4.1	550.0
231	87.0	575.0	245	57.5	850.0	313	13.3	337.5
232	46.0	675.0	246	13.1	350.0	314	6.3	412.5
234	409.0	1,150.0	325	102.0	850.0	315	0.0	325.0
339	21.0	275.0	337	86.0	750.0	316	4.0	350.0
340	36.0	450.0	338	50.0	750.0	318	3.3	275.0
351	14.0	575.0	348	24.5	337.5	322	0.0	250.0
356	16.7	400.0	354	19.5	387.5	323	3.3	312.5
357	34.0	1,200.0	346	52.5	925.0	324	21.3	312.5
Ave.	71.1	602.3		41.5	564.7		21.8	338.9

Both the total and active manganese content of the soils (Table 6) decreased in amount toward the east of Connecticut. A sample of soil collected in central Rhode Island strengthened this theory in that it showed only 1.6 p.p.m. of active and 150 p.p.m. of total manganese upon analysis.

The soil upon which manganese toxicity with tobacco was first observed was a Hollis silt loam from Woodbridge, Conn. This soil originated from easily weathered rock composed partly of phyllite schist. All the different kinds of rock found with the soil were analyzed for total manganese. The phyllite schist was the only rock in the soil which showed evidence, from the analysis, that it was the

chief source of the manganese. This rock had a content of 0.385% manganese. The soil itself had a total manganese content of 0.115%.

MANGANESE CONTENT OF LEACHATES FROM GREENHOUSE AND LYSIMETER SOILS

Leachates from lysimeter and greenhouse soils were determined for manganese content. The leachings were placed into two groups, one in which the reaction was below 6 pH and another in which they were above 6 pH. Twenty-five leachates whose reactions were below 6 contained an average of 11.55 p.p.m. of manganese. One hundred and four leachates with reactions above 6 had an average of 1.10 p.p.m. of manganese. All the foregoing leachings were from unlimed soils. Leachates from limed soils rarely contained manganese and when they did the amounts were very small.

DISTRIBUTION OF MANGANESE IN THE TOBACCO PLANT

Plant material was gathered from plants showing severe manganese toxicity symptoms. The material was analyzed for manganese content along with that of a normal plant. The results of the analyses are shown in Table 7.

TABLE 7.—*Manganese in different parts of a manganese-injured plant and a normal plant.*

Part of plant	Condition	Per cent manganese
Leaves	Normal	0.016
Roots	Normal	0.016
Upper leaves	Mn toxicity	0.400
Middle leaves	Mn toxicity	1.100
Lower leaves	Mn toxicity	0.800
Roots	Mn toxicity	0.317
Upper stems	Mn toxicity	0.081
Lower stems	Mn toxicity	0.106

The greatest percentage of manganese was found in the middle leaves (Table 7) of a manganese-injured plant. The upper leaves had the least. The percentage in the stems was small in comparison with the other parts of the plant.

CONCLUSION

The above report gave evidence to the following conclusions regarding Connecticut soils:

A high amount of active manganese in a soil was toxic to tobacco and manifested itself by producing plants with definite abnormalities.

Manganese toxicity symptoms occurred in tobacco plants when grown in solution cultures when the concentration of manganese was

as low as 1 p.p.m. When tobacco was grown in sand cultures, the application of 80 p.p.m. of manganese indicated toxicity in early stage of growth. In field tests 486 pounds of manganous sulfate to the acre failed to cause injury, which was probably due to the degree of acidity in the field soil.

Tobacco is a luxury feeder of active manganese.

Increased acidity of soils resulted in larger amounts of active manganese present and a greater intake of manganese by tobacco plants.

Total and active manganese content decreased in amount toward the east of Connecticut.

Leachates (water-soluble manganese) increased in manganese content with acidity increase.

The greatest percentage of manganese was found in the middle leaves and the least in the upper leaves of a manganese-injured tobacco plant.

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BOOK REVIEWS

THE VEGETABLE INDUSTRY

By H. A. Jones and S. L. Emsweller. New York: McGraw-Hill Book Co. VIII+431 pages, illus. 1931. $2.25.

This book is intended as a text book of high school grade "to give the beginner some idea of the importance of the vegetable industry." The vegetables are grouped and discussed by botanical families. At the end of each chapter are questions for classroom discussion, references to other books or bulletins, and suggestions for laboratory work. An interesting feature is a series of charts of the leading vegetables showing the volume of carlot production by states, and the seasons of production of the competing regions.

Photographs show principally irrigation methods, packages, insects, and diseases, but they are not well balanced. For example, there are 18 photographs of various phases of cantaloupe production, 14 of asparagus growing, 13 relating to lettuce, and 10 of cauliflower, while there are none of rhubarb, beets, chard, sprouting broccoli, Brussels sprouts, kohl rabi, winter or summer radishes, horse radish, lima beans, peas, okra, celeriac, parsley, parsnips, peppers, eggplant, salsify, and endive. To the reviewer it seems that photographs showing some of the less common vegetables would be very helpful to beginners.

Descriptions are given of a few commercial varieties of most of the vegetables, without regard to pointing out varieties that would illustrate the different types of each vegetable. A good seed catalog will give more information concerning varieties, and a mere listing of the few commercial varieties described in the text would have been better.

Although the different types of vegetable production are clearly defined in an early chapter, the descriptions of production methods are confined almost entirely to truck farming methods as practised in California. The fertilization of certain crops is given in good detail; but with many important crops this information is very meager or entirely lacking. Likewise, the recent progress in hill and row fertilization, particularly on corn and beans, has been overlooked.

The book contains much valuable information on the details of growing, irrigating, grading, and packing each crop and on controlling the principal insect pests and diseases. No doubt the emphasis on large-scale production will stimulate the interest of students. (C. B. S.)

A TEXT BOOK OF AGRICULTURAL ENTOMOLOGY

By Kenneth M. Smith. New York: The Macmillan Company, XIII+285 pages, illus. 1931. $4.25.

From the standpoint of American workers more distinctive titles for this book would be either Field and Garden Entomology or Insects Affecting Field and Garden Crops. As used in the title, the English term "agriculture" apparently does not include "horticulture" as is true of the American use of the word. With few exceptions, all the insects discussed are enemies of field and garden crops.

The author is to be congratulated for the accuracy, conciseness, and general excellence of this book. Under each species is usually given a brief description of the adult, egg, and larva, together with an account of the life history, natural enemies, and methods of control. In the case of the more important forms additional headings embrace distribution, cultivated host plants, wild host plants, description of injury to host plants, and symptoms of attacks. Each order of insects is concluded with a carefully selected list of references not only to the writings of British entomologists but also of foreign workers. The text is well illustrated with numerous half-tones and drawings of the insects and effects of their feeding on plants.

There are appended two excellent tables that should be of value to workers. The first is entitled "Characteristic Symptoms of Insect Attack" in which each crop is listed, together with the symptoms of injury whereby the insect cause is determined. The second gives a list of the common farm weeds of England which act as alternate hosts for many insect pests of farm crops. The work concludes with three indices, *viz.*, index of authors, index of parasites and predators, and a general index.

Although the book discusses insects common to the British Isles, many of these are also common pests in the United States and others are liable to be introduced, so knowledge of methods of control used in other countries may assist in formulating plans for the repression of the same or similar species in the United States. Just as the economic entomologist who gives practical directions for the control of insects attacking field crops should have a thorough grounding on the basic principles relating to the culture and economics of such crops, so the agronomist should have a general knowledge of the chief insect pests and fungous diseases of the various crop plants if he wishes to be of the greatest use in advising the public on varieties, planting time, and cultural practices. Dr Smith's book deserves a prominent place in the library of every agronomist and economic entomologist. (F. Z. H.)

AGRONOMIC AFFAIRS

NEWS ITEMS

RAY WALKER, a 1931 graduate of the Agricultural and Mechanical College of Texas, has been appointed to the fellowship recently established at the Texas Agricultural Experiment Station by the American Cyanamid Company, and will study the effect of fertilizers and the placement of fertilizers on the germination and yield of cotton on the alluvial soils along the Brazos River and on the soils of the black waxy region of Texas.

The fifth annual conference of scientists from the U. S. Dept. of Agriculture and from the Texas Agricultural Experiment Station engaged in the study of the cotton root-rot disease was held at the University of Texas, Austin, Texas, February 1 and 2, 1932. Thirty-four agronomists, soil technologists, chemists, pathologists, botanists, horticulturists, and other scientists were present and participated in the meeting. Fifty-five technical papers on the various phases of the root-rot investigations were presented. These papers dealt in detail with the physiological specialization of the root-rot fungus, its growth and nutrition;

sclerotial and spore stages of the fungus; host plants; infection and resistance; hibernation and transmission of root-rot; and occurrence of root-rot and estimation of losses. Studies on the control of root-rot of particular interest to agronomists included application of fertilizers, soil disinfectants, sub-soiling, rotations, crop barriers, and resistant species of plants.

DR. C. F. MARBUT, head of the Soil Survey of the U. S. Dept. of Agriculture, addressed the Agronomy Seminar at Cornell University recently on the subject of "Soil Conditions and the Adjustment of American Agriculture."

DR. W. P. HEADDEN, Chief Chemist of the Colorado Agricultural Experiment Station, died at his home at Fort Collins recently.

ON JANUARY 31 last, occurred the death of Professor George Janssen, Assistant Agronomist at the Arkansas Agricultural Experiment Station.

GLEN BURTON, who received his bachelor's degree (1931) in the Department of Agronomy, University of Nebraska, has accepted a fellowship in the Department of Soils and Crops, New Jersey College of Agriculture. He will pursue graduate work toward a master's degree under Dr. H. B. Sprague.

NELSON JODON, Junior Agronomist at the North Platte Substation in Nebraska, returned March 1 to the station after spending the winter months at Lincoln. Mr. Jodon received his master's degree at the close of the first semester.

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SUSCEPTIBILITY AND RESISTANCE OF WHEAT VARIETIES TO BUNT[1]

E. N. BRESSMAN[2]

Nearly 200 varieties of wheat were subjected in the fall of 1930 at Corvallis, Oregon, to the usual inoculation trials to determine their resistance or susceptibility to wheat bunt, *Tilletia tritici* (Bjerk.) Winter and *Tilletia levis* Kuhn. The inoculum used on this seed, however, consisted of a mixture of equal parts of the 10 physiologic forms of bunt reported by the writer.[3] The results were so striking and positive that they are presented at this time.

Most of the seed of these varieties was originally obtained from the U. S. Dept. of Agriculture to conduct a classification and identification nursery at Corvallis. Seed was retained from this nursery, so the varieties are pure and true to type. These varieties represented nearly all of the commercial varieties of wheat. Common, club, Poulard, durum, emmer, spelt, and Polish varieties were included.

All of the inoculum was obtained the previous year from the variety Hybrid 128. A large excess of the inoculum in dust form was added to small coin envelopes containing seed of each variety. The spores and seed were thoroughly mixed by shaking the envelope vigorously. The smutted seed was planted in single rows in the field in the fall of 1930 at Corvallis and head counts were made at harvest time. The mild winter conditions allowed both spring and winter types to survive. The results are given in Table 1.

[1]Contribution from the Farm Crops Department, Oregon State College, Corvallis, Ore. Published as Technical Paper No. 156 with the approval of the Director of the Oregon Agricultural Experiment Station. Received for publication August 3, 1931.

[2]Associate Agronomist.

[3]BRESSMAN, E. N. Varietal resistance, physiologic specialization and inheritance studies in bunt of wheat. Ore. Agr. Exp. Sta. Bul. 281. 1931.

TABLE 1.—*Percentage of bunt in various varieties of wheat fall sown after inoculating the seed with inoculum consisting of 10 physiologic forms of bunt, Corvallis, Oregon, 1930–31.*

C. I. No.	Name	Heads smutted	Total heads	Percentage of bunt
4636	Martin	89	92	97
4068	Prohibition	98	101	97
6320	Greeson	66	81	81
5219	White Winter	41	55	75
4682	Eaton	87	97	90
6450	White Wonder	68	80	85
6480	Early Defiance	38	49	78
4959	Colorado No. 50	34	58	59
6017	Touse	144	148	97
6477	Defiance	115	129	89
5868	Rink	94	107	88
5125	Bunyip	46	54	85
6221	Onas	94	102	92
4067	Pacific Bluestem	84	89	94
4762	Gypsum	70	75	93
2986	Surprise	90	97	93
3663	Dicklow	87	97	90
4990	Bobs	82	88	93
6157	Quality	20	65	31
4412	White Fife	51	65	78
4981	White Federation	66	75	88
6346	Lynn	57	60	95
3703	Regenerated Defiance	106	111	95
6011	New Zealand	92	98	94
5734	Rice	77	79	97
5149	Minhardi	77	84	92
3275	Lofthouse	57	94	61
3330	Buffum No. 17	25	76	33
4823	Leap	61	82	74
2907	Zimmerman	62	69	90
6445	Walker	52	67	78
5314	Harvest Queen	36	52	69
5380	Prosperity	50	68	74
6691	Forward	108	132	82
4509	Red Russian	107	112	96
6009	Sol	45	45	100
6301	Oakley	49	57	86
3549	Wyandotte	47	52	90
6307	Flint	140	151	93
6999	Fulhio	66	73	90
3416	Fultz	24	40	60
6692	Ashland	97	105	92
5657	Trumbull	115	128	90
4811	Fultzo-Mediterranean	77	85	91
1915	Purplestraw	105	109	96
5208	Huston	91	104	88
6688	Mosida	85	101	84
6935	Newturk	92	106	87
1438	Alton	106	115	92
6990	Michikof	69	74	93
6703	Ridit	13	77	17
6255	Red Bobs	53	68	78
8026	Supreme	93	104	89
3641	Marquis	71	78	91
6887	Marquillo	100	115	87
3329	Red Fife	51	58	88

TABLE I.—*Continued.*

C. I. No.	Name	Heads smutted	Total heads	Percentage of bunt
3697	Power	88	105	84
2873	Glyndon	65	75	87
1517	Ghirka	62	96	65
6047	Ruby	92	109	84
4800	Kitchener	73	84	87
6203	Climax	128	146	88
4337	Kofod	106	123	86
4655	White Odessa	111	133	83
6162	Honor	50	60	83
5942	Schonacher	54	80	68
5915	Windsor	60	77	78
2996	Goldcoin	58	81	72
5407	Allen	92	110	84
4734	Federation	53	65	82
5246	Foisy	117	125	94
4980	Hard Federation	77	84	92
6316	Gold Drop	68	87	78
3500	Red Wave	19	35	54
5996	Fleming	42	95	44
4475	Odessa	71	76	93
5920	Rupert	62	83	75
5921	Rural New Yorker No. 6	142	150	95
3326	Currell	125	136	92
3488	Poole	137	158	87
5654	Portage	154	172	90
5928	Russian Red	60	78	77
180	China	91	98	93
4816	Wheedling	71	82	87
6162	Shepherd	71	75	95
5336	Red May	86	94	91
5406	Illini Chief	76	89	85
3393	Red Clawson	46	71	65
5693	Rochester	51	68	75
3392	Red Chief	64	86	74
6013	Silvercoin	77	78	99
4489	Indian	75	101	74
5408	Triplet	116	124	94
3358	Mealy	84	88	95
4468	Jones Fife	90	92	98
2874	Haynes Bluestem	138	143	97
2398	Galgalos	46	70	66
3384	Democrat	137	159	86
4798	Palisade	83	89	93
1970	Propo	81	87	93
5332	Treadwell	98	118	83
1697	Baart	131	138	95
5147	Nebraska No. 28	48	50	96
5644	Gladden	115	137	84
3436	Gipsy	137	150	91
5923	Valley	57	63	90
5666	Sibley	64	77	83
4862	Fulcaster	116	131	89
6962	Nittany	83	104	80
2008	Mammoth Red	79	83	95
4782	Champlain	44	50	88
4966	Java	21	24	87
6902	Progress	68	90	75

TABLE 1.—*Continued.*

C. I. No.	Name	Heads smutted	Total heads	Percentage of bunt
2397	Erivan	29	43	67
4141	Converse	88	113	78
4430	Sherman	60	75	80
6155	Minturki	22	72	30
4843	Hussar	34	69	49
6251	Blackhull	124	131	95
1558	Turkey	29	66	44
8219	Ilred	102	105	97
5580	Iowa No. 404	66	76	87
6690	Minard	2	46	4
5549	Montana No. 36	28	30	93
6700	Karmont	23	30	77
6250	Nebraska No. 60	39	45	87
6683	Wisconsin Ped. No. 2	66	79	84
5146	Kanred	58	65	89
1667	Beloglina	7	74	9
5156	Bacska	12	62	19
7364	Regal	42	64	66
3328	Preston	109	131	83
7370	Reliance	52	67	78
5878	Kota	18	21	86
6900	Ceres	47	54	87
8178	Hope	39	79	49
4873	Rudy	42	52	81
5366	Niggar	86	102	84
2496	Silversheaf	34	46	74
1596	Fretes	33	37	89
1744	Genesee Giant	10	10	100
6282	Canadian Red	49	57	86
5823	Longberry No. 1	40	43	93
6247	Sevier	22	22	100
1395	Diehl-Mediterranean	82	90	91
5737	Russian	86	98	88
5338	Imperial Amber	65	74	88
4857	Goens	46	46	100
5240	Cox	49	49	100
6934	Iobred	10	50	20
6680	Ashkof	1	50	2
4795	Ladoga	21	38	55
5303	Mediterranean	81	99	82
8265	Denton	56	61	92
5597	Red Rock	57	66	86
3780	Webster	94	95	99
6401	Read	87	102	85
4323	Prelude	16	16	100
3690	Humpback	14	33	42
5948	Penquite	77	85	91
4512	Hybrid 128	70	80	88
8275	Albit	32	46	70
4066	Little Club	83	87	95
4257	Big Club	45	52	87
4160	Hybrid 143	74	81	91
4510	Hybrid 63	67	67	100
4511	Hybrid 123	42	50	84
5177	Jenkin	67	70	96
4241	Redchaff	84	90	93
5256	Bluechaff	10	23	43

TABLE 1.—*Concluded.*

C. I. No.	Name	Heads smutted	Total heads	Percentage of bunt
4155	Dale	19	19	100
3088	Coppei	3	12	25
6796	Wilbur	6	17	35
5988	Alaska	31	47	65
3322	Pentad	17	18	94
1584	Peliss	11	26	42
5284	Acme	1	7	14
6881	Akrona	4	27	15
3320	Monad	20	25	80
1494	Arnautka	5	26	19
5296	Mindum	27	41	66
1440	Kubanka	12	35	34
6519	Nodak	3	22	14
7287	Mondak	6	6	100
5295	Buford	41	42	98
1593	Marouani	40	41	98
2228	Velvet Don	7	26	28
5529	Kahla	16	17	94
1524	Vernal	18	32	56
2337	Black Winter	22	31	71
1773	Alstroum	26	27	96
3007	White Polish	29	62	47
8054	Superhard	26	27	96
8181	Garnet	29	62	47
8182	Reward	37	38	97
8276	Powers Club	71	73	97
8381	Purkof	66	77	86

An unusually large amount of bunt was obtained. It is unusual to obtain complete infection, but nine of the varieties were smutted 100%. No variety escaped infection entirely. Several of the varieties heretofore reported as resistant were susceptible and a few varieties were found to be resistant for the first time.

A description of practically all of the varieties is given by Clark, Martin, and Ball.[4] In this trial the most resistant varieties were Quality, Ridit, Minard, Beloglina, Ashkof, Bacska, Iobred, Acme, Akrona, Arnautka, Nodak, and Velvet Don. The durum varieties may have shown a low percentage of bunt because of the small number of heads in the row. Several of the foregoing varieties, however, had enough heads in the row to warrant the conclusion that they are worth considerable investigation as to their bunt resistance. It is hoped that this paper will stimulate other workers to test out the resistance of these varieties to many collections of bunt.

Both Quality and Ridit showed a characteristic partial bunting of the heads rather than the smutting of the entire heads as is the

[4]CLARK, J. ALLEN, MARTIN, JOHN H., and BALL, CARLTON R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.

usual case. In rather extensive trials reported on elsewhere,[5] Ridit has consistently shown this partial smutting of the heads. The same thing was strikingly shown in Quality.

Minard was of unusual interest. The two heads smutted in this variety showed much branching. They are illustrated in Fig. 1. No branching of healthy heads was observed in this variety and apparently the branching was caused by the smut organism. No similar case has been seen or reported so far as the writer knows.

FIG. 1.—Diseased and branbhed headson either side of a healthy head of Minàrd wheat.

Both Ashkof and Minard are described by Clark, Love, and Parker.[6] Ashkof was developed at the Ashland Branch Station of the University of Wisconsin. It is a selection from Malakof and is similar, with the exception of the glumes, which are brown. Minard was developed at the University of Minnesota as the result of a cross between Turkey and an unknown variety. Quality is a spring wheat and is the only spring wheat in these trials besides the durums which showed resistance.

Ridit, Minard, Ashkof, Beloglina, Bacska, and Iobred are winter wheats. All of them appear to be fairly satisfactory wheats wherever

[5]See footnote 3.

[6]CLARK, J. ALLEN, LOVE, H. H. and PARKER, J. H. Registration of improved wheat varieties. Jour. Amer. Soc. Agron., 18:922–935. 1926.

hard red winter wheats are desired. They show the resistance to smut which has been characteristic of the Turkey type of wheat.

The durum wheats are of spring habit and the susceptibility of many of the varieties may not be borne out in spring plantings. Even though some varieties appeared resistant, others showed high percentages of bunt, ranging from 80 to 100%.

It is of interest to note the susceptibility of varieties in all classes and chromosome groups of wheats. In general, more resistance is shown in the hard red winter and durum classes of wheats. Bunt is one disease that is no respecter of chromosome numbers and it interferes with the classification of the 14 and 21 chromosome groups on the basis of disease resistance.

Of course, additional work may show that all of these varieties are susceptible to other collections of bunt. The writer has found that Ridit is very susceptible to certain strains of bunt which he has obtained through selecting bunted heads and increasing the inoculum by returning it to the same variety. This same thing may be done with the other varieties, as none of them is entirely free of the disease.

Surely the bunt resistance problem is far more complicated than anyone realized a few years ago, especially if new physiologic forms are being obtained by mutation and hybridization. There are, however, some very desirable varieties, such as those indicated in the foregoing, that proved sufficiently free from bunt under the extremely severe test to which they were subjected in this trial to warrant the hope that a practical solution of the bunt problem may yet be arrived at through breeding, in spite of the diversity of bunt forms.

THE ORIGIN, NATURE, AND IMPORTANCE OF SOIL ORGANIC CONSTITUENTS HAVING BASE EXCHANGE PROPERTIES[1]

JOHN MITCHELL[2]

It is well known that both the organic and inorganic fractions of the soil play a rôle in its base exchange processes. Much of the investigational work, however, has dealt primarily with this phenomenon as it occurs in the inorganic soil material. The relative importance of each fraction in giving a soil its base exchange properties has not been studied quantitatively except in a limited way, and the possible nature of the substances present in soil organic matter which are responsible for its base exchange activity has had relatively little investigation. Some results obtained in a study such as is suggested by the above statement are reported in this paper.

REVIEW OF LITERATURE

While only a brief review of some of the literature more directly concerned with the subject of this paper is proposed, it seems advisable to mention one or two earlier papers. Konig (10)[3] noted that the brown, less decomposed peats had a higher absorptive capacity than the black peats, and that there was no absorption of the acid radicle except the phosphate. He also noted a higher absorption of ammonium from solutions of ammonium acetate and carbonate, than from solutions of ammonium chloride or sulfate. Van Bemmelen (16) pointed out that a sandy soil with sufficient organic matter might have as high absorptive power as a clay. The former worker believed the process of absorption to be chemical, while the latter thought it to be physical

Odén's (12) work on humic acid and other acids obtained by him from the organic matter of peats is well known. He considers humic acid to be tetrabasic, with an equivalent weight of about 340. The

[1]Contribution from Department of Soils, University of Wisconsin, Madison, Wis. Abstract of a thesis submitted to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication August 3, 1931.

[2]Fellow, Department of Soils, University of Wisconsin, and now Assistant Professor of Soils, University of Saskatchewan, Saskatoon, Canada. For the mano suggestions and helpful criticisms received, the writer is grateful to Prof. E. Truog, under whose general direction the work was done. The writer also wishes to express appreciation to Prof. K. P. Link for the helpful suggestions regarding some phases of the work.

[3]Reference by number is to "Literature Cited," p. 274.

small amount of nitrogen found in this humic acid is attributed to impurities. A more recent demonstration of the chemical nature of the exchange process of soil organic matter is seen in Kerr's (8) work, wherein he shows that the same mass action equation which was applicable to mineral exchange compounds in equilibrium studies could be applied to the exchange reactions of a peat. The latter observation is of importance to the subject matter of this paper, since an important phase of this study was the determination of the calcium-magnesium mass action equilibrium constants for the organic exchange complex of a number of peat and mineral soils.

The question of the nature of the compounds functioning in the base exchange reaction may be linked with the question of the origin of soil organic matter. Du-Toit and Page (2) and Waksman (17) have furnished evidence in support of the possibility that plant lignin is the material from which much of the soil humus is derived. Waksman (17) considers that there is a nitrogen-poor fraction of the humus from this source and a nitrogen-rich fraction derived from the tissue of soil organisms, such as the fungi.

Shorey (14) gives the distribution of nitrogen in the humus fractions of Washburn loam as obtained by treatment with 2% sodium hydroxide. All fractions obtained in the first steps contain nitrogen, but it is possible to obtain nitrogen-free compounds from some fractions, as this writer points out. That much of the soil humus is resistant to 72% sulfuric acid as used in the determination of lignin is well known.

Feustel and Byers (3) give the "lignin-humus" content of a number of peat profiles as determined by the above method. The content of "lignin-humus" is quite high in all samples except the sphagnum peats. The nitrogen content of the "lignin-humus" is shown as varying from 0.20% to over 2.0%.

McGeorge (11), in investigating the nature of the compounds functioning in the exchange reactions of humic matter, shows a direct relationship between carbon content, and also lignin content, and base exchange capacity. No such relationship appears between the content of nitrogen, cellulose or hemicellulose, and base exchange capacity.

Concerning the possible importance of soil organic matter in giving the soil base exchange capacity, Gedroiz (4) suggests that the humus portion of the soil may have a greater effect than the mineral portion. Hissink (6) points out the high absorptive power of humus, while Kerr (8) and Sokolovski (15) have given evidence that the humus fraction of mineral soils has a decided effect in giving base exchange capacity to them.

MASS ACTION EQUILIBRIUM CONSTANTS OF THE SOIL ORGANIC EXCHANGE COMPLEXES AND THEIR SIGNIFICANCE

Kerr (8) determined the mass action equilibrium conditions for a peat by first saturating the exchange complexes with calcium, and then placing samples of a suitable size in contact with solutions of magnesium chloride for a sufficient time to allow the system to reach equilibrium. From a knowledge of the total exchange capacity of the peat, the amount of calcium displaced by magnesium, and the final concentration of the solution in magnesium, he was able to calculate the equilibrium constant K, according to the equation $\frac{(Mg{+}{+})\ (CaX)}{(Ca{+}{+})\ (MgX)} = K$, where X represents the active mass of the base exchange complexes. The value of K, as determined by a number of trials, was quite close to a constant. In making further studies, Kerr (9) modified his method of determining K by treating the material under investigation with a solution which was half normal with respect to both calcium and magnesium chloride. This allowed the calculation of K to be simplified to a determination of $\frac{CaX}{MgX}$. Kerr (9) also found that the calcium-magnesium equilibrium constant of the mineral exchange material had the same numerical value in all the soils studied. This was taken as an indication that only one mineral base exchange compound was commonly to be found in the soil.

It was thought that a determination of the calcium-magnesium constant for the organic matter of a number of peat and mineral soils might be of interest, and might be used as a criterion of whether or not the complexes responsible for base exchange in the organic fraction of soils were variable from soil to soil. Such a study involves determining the calcium and magnesium retained by the organic complexes, by a method of difference, in all cases where the mineral matter present has exchange capacity. It is recognized that such a method increases the possibility of error in the results.

THE CALCIUM-MAGNESIUM CONSTANTS

In the preliminary studies by method No. 1, 5- or 10-gram samples of mineral soils and 2 grams of peaty soils were leached with a litre of a solution half normal with respect to both calcium and magnesium chlorides. They were then washed free of chlorides with distilled water, leached with a litre of normal ammonium chloride solution, and the displaced calcium and magnesium determined in the leachate. Duplicate determinations, as shown in Table 2, were made by re-

peating this procedure on the same sample. For the determination of the amount of calcium and magnesium retained by the inorganic complex, the organic matter was destroyed by ignition at a low temperature in an electric furnace fitted with an electric pyrometer. The organic complex may also be destroyed by hydrogen peroxide with repeated treatments. However, the process is a longer one and the residue is difficult to leach, owing to the high degree of dispersion resulting from the treatment. It is also difficult to ascertain if oxidation is complete by this method. A comparison of the results obtained by the two methods with somewhat varied conditions is given in Table 1.

TABLE 1.—*A comparison of the H_2O_2 method, and the ignition method for the destruction of soil organic matter in base exchange studies.*

Soil used	H_2O_2 method		Ignition method	
	Strength of H_2O_2 used %	Exchange capacity after treatment (milli-equivs. per 100 grams)	Temp. of ignition, °C	Exchange capacity after ignition (milli-equivs. per 100 grams)
A dark grey silt loam from Sask. .	15	14.8	350°–400°	15.0
A dark grey loam from Sask.	15	10.6	350°-400°	10.6
Carrington silt loam from Wis	15	10.6	500°–550°	8.2
A dark loam from Sask.	3	10.1	350°–400°	8.4

The data indicate that ignition at 350° to 400° C for 7 or 8 hours, which usually produces a well-oxidized sample, does not destroy or change the base exchange capacity of the inorganic material. The work of Kerr (9) and of Kelley, Dore, and Brown (7) may be quoted in support of this method. The latter workers showed that the base exchange capacities of the soil zeolite and two bentonites studied were not affected by ignition at 350°C. Ignition at 350° to 400°C until the sample appeared to be well oxidized has therefore been used as a means of removing the organic matter in this investigation. The determination of the calcium and magnesium retained by the inorganic complex was made in a manner similar to that described for the total soil, with the difference that 10-gram samples were ignited in the case of peats.

The amounts of calcium and magnesium retained at equilibrium by the untreated sample, and that retained by the ignited sample under the same conditions, were calculated to a milli-equivalent

basis per 100 grams of untreated material. The calculation of K for the organic complexes then resolved into
$\frac{\text{Ca total—Ca inorganic}}{\text{Mg total—Mg inorganic}} = K$, as is seen by a consideration of the equilibrium equation already given. Since each determination furnishes the information required to calculate the constant for the inorganic complex, these data have been included in the study. The agreement seen in these studies with the calcium-magnesium constant for the inorganic complex as determined by Kerr (9) is notable.

The results of the preliminary determinations of the calcium-magnesium equilibrium constant for the organic base exchange complexes of the soils studied are given in Table 2. The study reveals that the value of the constant differs considerably for different soils.

It was thought advisable to extend this investigation to include a few more soils, and in doing so a somewhat modified method was employed. It seemed possible that the method used might not give complete saturation of the exchange complexes. This was particularly probable in the case of the peat samples Nos. 1 and 2, which were both fairly acid in reaction, and of the Saskatchewan samples which required pretreatment with acid (0.05 N hydrochloric was used) in order to remove calcium carbonate.

Chapman and Kelley (1) have shown that a solution of ammonium acetate may be used to replace hydrogen fully from the exchange complexes Accordingly, in order to insure removal of this difficultly replaceable ion and to provide for easier saturation of the complexes by calcium and magnesium, it was decided to use ammonium acetate as a pretreatment in the new determinations. A slight modification introduced was to leach the samples a few times at the beginning of the treatment with normal ammonium carbonate solution This modification was inserted in the procedure in order to insure quick neutralization of any free acid which might not have been removed after a previous treatment with acids.

The method used in determining the equilibrium constants and exchange capacity from this point in the investigation, and designated as method No. 2, was as follows:

For the determination of the total calcium and magnesium retained, 5-gram samples of mineral soils and 1-gram samples of peats were used. For the determination of that retained by the mineral complex, 5-gram samples of mineral soils and 10 grams of peat were ignited. The samples were placed on a folded filter paper in a funnel and treated seven or eight times with normal ammonium acetate

TABLE 2.—*Preliminary determinations showing the range in the Ca-Mg equilibrium constants for the organic exchange complexes of different soils, method No. 1.*

Sample No.	Soil	Total Ca and Mg retained at equilibrium (milli-equivs. per 100 grams)		Ca and Mg retained by inorganic fraction (milli-equivs. per 100 grams)		$K.\left(\frac{Ca}{Mg}\right)$ organic	$K.\left(\frac{Ca}{Mg}\right)$ inorganic
		Ca	Mg	Ca	Mg		
1	Brown peat, Wis	86.50	28	nil	nil	3.1	—
		84.00	28.8	nil	nil	2.9	—
2	Black peat, Wis	34.70	12.9	1.85	1.70	2.9	1.10
		39.50	14.1	1.85	1.70	3.0	—
3	A dark grey silt loam, Sask	28.20	12.55	7.95	7.05	3.7	1.13
		25.42	11.55	7.57	6.94	3.9	1.09
4	Dodgeville silt loam, Wis	14.90	7.70	4.13	3.82	2.8	1.08
5	Carrington silt loam, Wis	13.50	6.02	3.66	2.97	3.2	1.23
		13.52	6.20	4.60	3.65	3.5	1.26
6	Greyish yellow loam, Ky	3.66	2.58	1.80	1.74	2.2	1.08
		4.31	3.08	2.48	2.13	1.9	1.16
7	Poulouse silt loam, Wash	11.68	6.94	3.86	3.01	2.0	1.28
		11.30	6.84	4.15	3.22	2.0	1.28
8	Waukesha silt loam, Wis	14.43	7.16	4.52	3.54	2.7	1.27
		15.10	7.86	4.95	4.00	2.6	1.24

solution adjusted to pH 7.2. They were then leached three times with normal ammonium carbonate solution and several times again with the ammonium acetate solution, transferred to Erlenmeyer flasks, and left in contact with 100 cc of the ammonium acetate for 12 hours. The samples were returned to the same funnel and leached 5 times with ammonium acetate, then with 300 to 400 cc of calcium and magnesium chloride solution, half normal with respect to each. The excess calcium and magnesium chloride was removed by washing with distilled water until the last trace of chlorides had disappeared. The calcium and magnesium were then replaced by leaching with 300 to 400 cc of the normal ammonium acetate solution. This leachate was taken to dryness on the steam bath, thus removing the ammonium acetate. If organic matter was present in the leachings it was destroyed by adding a few cc of hydrogen peroxide to the dry residue and taking to dryness again. The calcium and magnesium were then determined by standard methods. The calculations were made as before. It should be pointed out that the sample must necessarily be free of calcium which might be precipitated by the ammonium carbonate; also, that in leaching with the calcium-magnesium solution and with the displacing solution, each portion added was allowed to drain completely through the filter before adding more solution.

The results of this further investigation, together with a description of the soils used are given in Table 3. Included also in Table 3 are re-determinations of the constant on samples Nos. 1, 2, and 3 by method No. 2. As was expected, a notable increase in the base exchange capacity is seen. The increase is relatively small, however, in the case of the mineral soil, so it is considered that the remainder of the mineral soils included in Table 2 were sufficiently near complete saturation with calcium and magnesium by the method used. The constants obtained by these re-determinations are slightly lower than those shown in Table 2. The differences are probably not great enough to be significant, however. The variation in the calcium-magnesium constant for the organic complex is of about the same magnitude as before, and this variation in the results shown in the two tables indicates that there is more than one compound concerned in the base exchange reactions of soil organic matter. The variation in the constant could be produced by two or more compounds being present in differing proportions. However, the data reveal that the majority of the soils studied have a constant in the neighborhood of 3. This suggests that the mixture of compounds responsible for the exchange process may be similar in these particular cases.

TABLE 3.—*Further determinations of the Ca-Mg equilibrium constant for the organic exchange complexes of soils, method No. 2.*

Sample No.	Soil	Total Ca and Mg retained at equilibrium (milli-equivs. per 100 grams)		Ca and Mg retained by inorganic complex (milli-equivs. per 100 grams)		$K.\left(\frac{Ca}{Mg}\right)$ organic	$K.\left(\frac{Ca}{Mg}\right)$ inorganic
		Ca	Mg	Ca	Mg		
9	Brown peat, Sask	123.5	46.5	nil	nil	2.7	—
10	Black peat, Wis.	44.3	18.4	1.75	1.55	2.5	1.10
11	Dark silty clay loam, Sask	26.25	14.75	12.30	11.10	3.8	1.11
12	Dark loam, Sask.	15.55	8.30	6.17	5.74	3.7	1.08
13	Dark loam, Sask.	17.90	10.85	8.40	7.70	3.0	1.09
14	Dark brown loam, Sask	16.85	9.20	6.75	6.22	3.4	1.08
		Re-determinations					
1	Brown peat, Wis.	117.0	45.0	—	—	2.6	—
2	Black peat, Wis.	63.6	26.6	1.85	1.70	2.5	—
3	A dark grey silt loam, Sask.	30.7	14.4	8.65	7.90	3.4	—

EFFECT OF EXTRACTIONS WITH ORGANIC SOLVENTS

There are three soils, namely, Nos. 3, 11, and 12, which give a higher value for the calcium-magnesium constant of the organic exchange material than is seen for the other soils studied. It was thought possible that this might be due to the presence of free organic acids other than the acids of the exchange complexes, possibly of the nature of fatty acids. Accordingly, soil No. 12 was extracted for several hours with ether and refluxed for several hours with a mixture of equal parts of benzene and ethyl alcohol. The base capacity and the calcium-magnesium constant were determined after this treatment and were found to be as follows: Total base exchange capacity (milli-equivs. per 100 grams), 22.5; K. $(\frac{Ca}{Mg})$, 3.8.

The results given in Table 2 show this soil to have a total base exchange capacity of 23.8 milli-equivalents per 100 grams and a constant of 3.7. There is therefore no significant effect on either the total capacity or the equilibrium constant of this soil from extracting with the organic solvents mentioned above.

While the extraction of this soil with ether and an alcohol and benzene mixture appears to have had no effect on the base exchange complexes, there did seem to be a distinct effect on the solubility or dispersability of the organic matter in water. The extract in the case of treatment by the organic reagents used was but little colored. On leaching with water following this treatment a very highly colored extract was obtained, although leaching with water previous to the extraction gave a clear filtrate. Shorey (14) noted this phenomenon in making an alcoholic extraction of a peat and concluded that it is due to a dispersion of some organic material following a removal of cementing substances by the organic reagents. This explanation appears to be satisfactory. It is a further illustration of the complexity of the system of organic compounds making up soil organic matter.

PROPORTION OF TOTAL BASE EXCHANGE CAPACITY DUE TO SOIL ORGANIC MATTER

The data obtained in determining the equilibria constants for the organic complexes as given in Tables 2 and 3 allow the calculation of the proportion of the total base exchange capacity which is due to the organic complexes alone. In Table 4 the loss on ignition at low red heat is given, together with the percentage of the total base exchange capacity due to the organic complexes. Included also in this table is a column giving the base exchange capacity of the organic

matter of each soil and peat, calculated as milli-equivalents per 100 grams of organic matter.

TABLE 4.—*The percentage of the total base exchange capacity due to the organic matter, and the difference in the exchange capacities of the organic matter of the different soils studied.*

Sample No.	Percentage loss on ignition	Total exchange capacity (milli-equivs. per 100 grams)	Exchange capacity due to inorganic material (milli-equivs. per 100 grams)	Percentage exchange capacity due to organic matter	Exchange capacity of 100 grams organic matter (milli-equivs.)
1*	87.3	162.0	nil	100	185
2	60.0	90.2	3.5	96	145
3	16.1	45.1	16.5	64	177
4	9 2	22.6	7.95	65	159
5	9.6	19.6	7.2	63	130
6	4.0	6.8	4.0	41	70
7	6.4	18 4	7.1	61	176
8	11.6	22.3	8.5	62	119
9	88 9	170.0	nil	100	191
10	53 5	67 8	3.2	95	121
11	12.1	41.0	23.4	43	145
12	9.0	23 8	11.9	50	132
13	8.0	28.7	16.1	44	200
14	11.5	26.0	13.0	50	113

*Nos. 1, 2, 9, and 10 are peat samples.

This table shows that in the mineral soils studied, the proportion of the total base exchange capacity of the soils due to the organic complexes ranged from 41 to 65%. These are all soils of medium texture. It is quite likely that sandy soils would show still higher percentages of the base exchange capacity as due to the organic complexes if they contained any considerable amount of organic matter. Samples Nos. 2 and 10, for instance, are peats with a high percentage of mineral matter most of which is sand. The mineral exchange capacity, however, was so small (about 3 milli-equivalents) that it could almost be disregarded without seriously affecting the results in calculating the calcium-magnesium constant.

The last column in Table 4 is of interest. Here the base exchange capacity of the organic matter as determined by loss on ignition is calculated to milli-equivalents per 100 grams. The variation in the base exchange capacity of the organic matter from different samples on this basis is very great. McGeorge (11) in a similar study shows that there is a relationship between the loss in carbon by hydrogen peroxide treatments and loss in base exchange capacity, but none between the residual organic carbon and base exchange capacity determined after the treatments.

PROBABLE NATURE OF ORGANIC SUBSTANCES INVOLVED IN BASE EXCHANGE REACTIONS

The view that lignin is an important source of the humic matter of soils appears to be well supported. The exact chemical changes occurring in the formation of humus from the plant materials are unknown, as is the chemical structure of lignin itself. The microorganisms producing decomposition of organic material in the soil are at the same time active in synthesizing tissue which in its turn will suffer decomposition. Final equilibrium in all these processes is probably never reached in a soil, but the production of a more resistant, highly complex organic material generally designated as humus is quite universal.

Feustel and Byers (3) have investigated a fairly large number of peat profiles obtained from different places in the United States. In their analytical studies, besides reporting the percentage of "lignin-humus" complexes, these writers report cellulose, hemi-cellulose, and the total fraction hydrolyzable by 2% hydrochloric acid. These fractions make up the greater part of the organic material of the peats studied. The water, alcohol, and ether-soluble fractions are relatively small. The "lignin-humus" fraction is the largest fraction, except in the case of the sphagnum peats where the fraction hydrolyzable by 2% hydrochloric acid is shown to be larger. The hemicellulose makes up about 50% of this hydrolyzable fraction, but is usually less than 50% in the case of the peats higher in "lignin-humus" material. When consideration is given to the fact that the organic matter of soils is often capable of retaining 3% of its weight in replaceable calcium, there seems reason to expect that some of the larger fractions would be responsible for this phenomenon. Even if the complexes active in base exchange processes have a relatively small equivalent weight, it would be required that a large percentage of the total organic material consist of these complexes. For instance, if the equivalent weight were 340 (Odén's humic acid), in order for the organic matter of a soil to retain 3% of its weight of elemental calcium, it would be necessary that about one-half of the organic matter be made up of this substance.

Since the "lignin-humus" fraction as designated by Feustel and Byers (3) is apparently an important fraction in peats, at least and since a large portion of soil organic matter may have its origin from plant lignin, attention naturally turns to an examination of this material as to possible base exchange capacity. McGeorge (11) reports data for such an investigation with corn cob lignin. The original exchange capacity of 20 milli-equivalents per 100 grams was

capable of being greatly increased by treatments with slightly alkaline salt solutions. He showed also that "soil lignin," prepared by extracting the soil with alcoholic sodium hydroxide and "soil lignin hemicellulose," prepared by extracting with aqueous sodium hydroxide, had a high base exchange capacity. The material extracted by the aqueous sodium hydroxide had a considerably higher base exchange capacity than the other preparation.

Lignin was prepared from spruce sawdust by the method given by Schorger (14), and the calcium-magnesium constant and total base exchange capacity determined on a sample by method No. 2. The total base exchange capacity was found to be 18 milli-equivalents per 100 grams, and the calcium-magnesium constant had a value of 2.0. A sample of pine wood partially decomposed by a brown rot organism (*Poria incrusatta* (B & C) Burt), obtained by courtesy of the Forest Products Laboratory, at the University of Wisconsin, was found to have a base exchange capacity of 30 milli-equivalents and a calcium-magnesium constant of 2.1. The lignin content of this sample was 44%. The similarity of the constants for the lignin by 72% sulfuric acid and for the brown rot wood suggests that here also the lignin is the active substance. However, its base exchange capacity is much greater in the latter case.

LIGNIN, "LIGNIN-HUMUS," AND THE EFFECT OF WEAK ACID HYDROLYSIS

It appeared from the above results that data of interest might be obtained from a study of the base exchange capacity of the "lignin-humus" material prepared from peat soils. Samples Nos. 1, 2, 9, and 10 were used in this study. The method of preparation of the "lignin-humus" material was essentially that given by Schorger (13) for the determination of lignin. Ten-gram samples of the peat were extracted with acetone for several hours, filtered, and dried. They were then treated with 200 cc of 72% sulfuric acid solution in 500-cc Erlenmeyer flasks and allowed to digest at room temperature. The flasks and contents were cooled in a stream of water at the beginning of the reaction. The solution was diluted to 2 litres and boiled 2 hours, filtered, and the "lignin-humus" material washed free of acid. The residue was dried at room temperature and the ash determined by ignition of one small sample, while nitrogen was determined on another. Table 5 gives the data obtained from this investigation.

The percentage of "lignin-humus" material is given in terms of the ash-free organic matter originally present, and represents the residue obtained after treatment with 72% sulfuric acid, less the ash. It

TABLE 5.—*The percentage of "lignin-humus" material in the organic matter of samples of peat soils and the nitrogen content of this material.*

Sample No.	Percentage ash in sample	Residue from 10 grams after 72% H_2SO_4, grams	Ash in residue after treatment, grams	Percentage "lignin-humus" material in organic matter	Percentage nitrogen in "lignin-humus" material
1	12.7	5.937	0.617	61 0	2.64
2	40.0	7 432	3.600	64.0	2.18
9	11.1	5.550	0.795	55 5	2.13
10	46.5	7.446	4 160	61.5	2.25

therefore includes the "crude proteins" of this fraction. The percentage of nitrogen as determined on the ash-free basis is also included in Table 5. The base exchange capacity and the calcium-magnesium constant for the "lignin-humus" material were next determined. The results of this study are given in Table 6. For the purpose of comparison, the base exchange capacity of the original sample calculated as milli-equivalents per 100 grams ash-free basis is given. The base exchange capacity shown for the "lignin-humus" residue is also calculated on an ash free basis. The calcium-magnesium constant is given for each case Assuming that the "lignin-humus" fraction has the same capacity after treatment with 72% sulfuric acid as in the original sample, the amount of the total base exchange capacity due to "lignin-humus" material may be calculated. This calculation has been included in Table 6. The data of Tables 5 and 6 are noteworthy in several points.

TABLE 6.—*The base exchange capacity and Ca-Mg equilibrium constant of the "lignin-humus" material from samples of peat soils and the amount of the original capacity due to this material.*

Sample No.	Capacity of 100 grams original organic matter (milli-equivs.)	Capacity of 100 grams "lignin-humus" material (milli-equivs.)	Amount of original capacity due to "lignin-humus" material (milli-equivs)	K. $\left(\frac{Ca}{Mg}\right)$ for "lignin-humus" material
1	185	182	111	2.1
2	145	176	113	2.1
9	191	252	140	2.5
10	127	150	92	2.2

The base exchange capacity of the "lignin-humus" material from the samples investigated is even more variable than the base exchange capacity of the original untreated samples. The base exchange capacity shown by the "lignin-humus" material appears to bear a relationship to the capacity shown by the original sample. The

nitrogen content appears to have no relationship to the base exchange capacity of the "lignin-humus" material. The base exchange capacity of the original sample calculated as due to the "lignin-humus" material is much less than the original capacity. However, the larger portion of the total base exchange capacity is due to the "lignin-humus" fraction, as is shown by the calculations given in Table 6.

Since there appeared to be a possibility that some of the complexes of soil organic matter responsible for base exchange might be contained in the fraction hydrolyzable by dilute acids, samples Nos. 1, 2, 9, and 10 were subjected to the following treatment. One-gram samples were treated at boiling temperature with 100 cc of 2% hydrochloric acid for 5 hours. After filtering and washing free of excess acid, they were treated as in method No. 2 for the determination of base exchange capacity and the calcium-magnesium constant. The results of this investigation are given in Table 7. The base exchange capacity is expressed in milli-equivalents per 100 grams organic matter based on the weight before hydrolysis. The calcium-magnesium constant is given in each case On comparing the base exchange capacity after hydrolysis with that calculated as probably due to "lignin-humus" material, there appears to be a rather close agreement in at least three cases. Furthermore, the values of the calcium-magnesium constants appear to approach closely to those obtained for the "lignin-humus" fraction.

TABLE 7.—*The effect of weak acid hydrolysis on the base exchange capacity of samples of peat soils and the Ca-Mg equilibrium constants after hydrolysis.*

Sample No.	Capacity of 100 grams original organic matter (milli-equivs.)	Capacity after hydrolysis (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$ after hydrolysis
1	185	141	2.2
2	145	129	2.2
9	191	139	2.6
10	127	111	2.1

It was thought possible that there might be a slow destruction of base exchange capacity both from treatment with 72% sulfuric acid and from dilute acid hydrolysis. The 1-gram samples of "lignin-humus" material from samples Nos. 1, 9, and 10, which had been used for the determination of base exchange capacity, were re-treated with 72% sulfuric acid as in the former "lignin-humus" determination. At the same time the 1-gram hydrolyzed samples Nos. 1, 9, and 10 were re-treated as in the previous hydrolysis. The base exchange capacity and calcium-magnesium constants were determined on all samples as before, and then the treatments

and determinations were once more carried out on the same samples. Each gram sample of "lignin-humus" material from soils Nos. 1, 9, and 10 had now been treated three times as in the method described for the "lignin-humus" determination and each 1-gram hydrolyzed sample had received three separate hydrolyses, the base exchange capacity and the calcium-magnesium constant being determined after each treatment. The data resulting from this study are given in Table 8. The data in this case are expressed in milli-equivalents per 100 grams of the untreated sample. The base exchange capacity after the first hydrolysis, and also that of the "lignin-humus" material, as given in Tables 6 and 7, are calculated to this basis and included in Table 8 for purposes of comparison.

From a consideration of the data of Table 8 it seems that there are two definite fractions of the organic matter of soils responsible for base exchange capacity. The base exchange capacity after hydrolysis is very close to the capacity which may be calculated by a knowledge of the base exchange capacity of the "lignin-humus" material, and the percentage of it present. It appears also that the hydrolysis should be continued for at least 10 hours in order to remove completely the material responsible for the base exchange capacity of the hydrolyzable portion, while the 72% sulfuric acid treatment should be of 30 or 36 hours duration. The effect of the cellulose fraction is negligible in giving base exchange capacity to the organic matter, since the weak acid hydrolysis would leave this fraction intact while the 72% sulfuric acid treatment would destroy it.

A further proof of the small activity of cellulose in base exchange processes appears in the determination made on cellulose prepared from spruce wood by the phenol method as given by Hillmer (5). In this method there is solution of lignin and other fractions in the presence of a small amount of hydrochloric acid, the cellulose remaining as an undissolved fraction. The base exchange capacity of this cellulose was only 4 milli-equivalents per 100 grams.

To obtain some further data on the effect of hydrolysis and 72% sulfuric acid treatments on the base exchange capacity and calcium-magnesium constants of peat soils, three new samples were obtained and each treated as follows: One gram was untreated except to determine total base exchange capacity and the calcium-magnesium constant, 1 gram was hydrolyzed for 10 or 12 hours with 100 cc of 2% hydrochloric acid, and 1 gram was treated with 40 cc of 72% sulfuric acid for 36 hours, the solution then being diluted to 400 cc and boiled 2 hours. The residues of these two treatments were filtered off and their calcium-magnesium constant and total base exchange capacity

TABLE 8.—*The effects of repeated hydrolyses and 72% H_2SO_4 treatments on the base exchange capacity of samples of peat soils and the Ca-Mg constant after each treatment.**

Sample No.	Treatment	1st treatment		2d treatment		3d treatment	
		Capacity (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$	Capacity (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$	Capacity (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$
1	Hydrolysis	123	2.1	92	2.3	86	2.2
	72% H_2SO_4	98	2.1	82	2.3	83	2.0
2	Hydrolysis	77	2.2	—	—	—	—
	72% H_2SO_4	67	2.2	—	—	—	—
9	Hydrolysis	123	2.6	111	2.6	107	2.4
	72% H_2SO_4	125	2.5	118	2.5	114	2.3
10	Hydrolysis	59	2.1	53	2.2	50	2.2
	72% H_2SO_4	50	2.1	42	2.1	42	2.0

*Capacity expressed on the basis of 100 grams of untreated sample.

TABLE 9.—*Further studies on the effect of hydrolysis and 72% H_2SO_4 treatments on the base exchange capacity and the Ca-Mg constants of peat soils.**

Sample No.	Description	Untreated		Treated			
				Hydrolyzed 10 hours with 2% HCl		72% H_2SO_4 for 36 hours	
		Base exchange capacity (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$	Base exchange capacity (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$	Base exchange capacity (milli-equivs.)	K. $\left(\frac{Ca}{Mg}\right)$
15	Dark brown peat, Wis	146	2.7	89	2.3	94	2.2
16	Dark brown peat, Wis	120	2.3	94	2.0	83	2.0
17	Dark brown peat, Minn	123	2.4	92	2.1	91	2.0

*Capacity expressed on the basis of 100 grams of untreated sample.

determined as before. The data obtained are given in Table 9, the results being expressed in milli-equivalents per 100 grams of the original sample. The conclusion that the base exchange capacity of soil organic matter is partly destroyed by weak acid hydrolysis, and that the remainder is residual in the "lignin-humus" material, is well substantiated by these results.

McGeorge (11) found no direct relationship between hemi-cellulose content and base exchange capacity. A consideration of Feustel and Byers (3) results shows the hemi-cellulose content of the weak acid hydrolyzable fraction to be less than half of the total fraction in most of the analyses reported. It appears possible that there is some other constituent of this fraction which is active in base exchange processes. In the four peat soils investigated in this study it is seen that the "lignin-humus" material is responsible for the larger percentage of the total base exchange capacity. The more highly decomposed peats appear to have a higher percentage of base exchange capacity from this source than the less decomposed. The "lignin-humus" material, as designated in this paper, contains a considerable percentage of nitrogenous compounds, as is indicated by the nitrogen content given in Table 5. That the base exchange capacity does not appear to vary directly with the amount of nitrogen present has already been pointed out. The nitrogen-free fraction of the "lignin-humus" material is therefore likely to contain the material responsible for its exchange properties, and this fraction is also the fraction probably derived from plant lignin. An examination of the value of the calcium-magnesium constant after hydrolysis and after treatment with 72% sulfuric acid gives further support to the theory that lignin, or a derivative of very similar nature, is the constituent which gives the "lignin-humus" material its base exchange properties.

It is seen that for all cases the calcium-magnesium constant has about the same value. Furthermore, this value is in good agreement with the value of the constant found for prepared lignin and for wood undergoing decomposition by cellulose-destroying organisms. It appears of some significance that soils Nos. 6 and 7 should give a constant agreeing with that for lignin, etc. The indication is that in these two cases the hydrolyzable fraction responsible for base exchange is absent, or nearly so. Since this fraction is a less resistant one, it is not strange that under some conditions it might fail to accumulate to any extent. Such factors as the nature of the plant material from which the soil organic matter was derived, the climatic conditions under which it was decomposed, and the nature of the

organisms causing decomposition would probably affect the accumulation of this material. It will be noted that soils Nos. 6 and 7 are the lowest in organic matter of any studied.

EFFECT OF EXTRACTIONS WITH 0.5 N SOLUTIONS OF BASES

Somewhat relative to this discussion are the following experiments: Two grams of peat sample No. 1 were treated with a 0.5 N ammonium hydroxide solution for 24 hours, filtered, and the base exchange capacity and calcium-magnesium constant determined. A similar sample was treated with 0.5N NaOH and similar determinations made. The results, given in milli-equivalents per 100 grams original material, were as follows:

Base exchange capacity after extraction with 0.5 N NH_4OH	K. $\left(\frac{Ca}{Mg}\right)$	Base exchange capacity after extraction with 0.5 N NaOH	K. $\left(\frac{Ca}{Mg}\right)$
108	2.4	25	2.0

The loss in base exchange capacity is markedly greater in the case of the sodium hydroxide treatment. Various workers have pointed out that these bases differ in their effect in extracting humus, so that a difference in their effect in extracting the organic base exchange capacity material is more or less to be expected. The fact that the calcium-magnesium constant has a value similar to that found for the "lignin-humus" fraction leads to the conception that the action of these bases is to remove first the fraction hydrolyzable by dilute acid. In fact, the ammonium hydroxide treatment leaves a residual base exchange capacity of about the same magnitude as that found after hydrolysis by 2% hydrochloric acid.

Odén (12), McGeorge (11), and others have shown that undecomposed plant materials have base exchange capacity. In the course of this investigation the base exchange capacity was determined for a sample of spruce sawdust ground to an impalpable powder, a finely ground sample of wild marsh hay largely consisting of sedges, and a finely ground sample of rye straw. The results in milli-equivalents per 100 grams were as follows: Sawdust, 10; marsh hay, 17; and rye straw, 12. The base exchange capacity shown is relatively small, but definite. The marsh hay and rye straw were not so finely ground as the sawdust. It is possible that finer grinding would have increased this capacity slightly.

SUMMARY

The results of these studies may be summarized as follows:

1. The calcium-magnesium equilibrium constants for the organic base exchange reactions have not the same value in all soils. This

fact indicates that more than one compound is responsible for base exchange reactions in soil organic matter.

2. The organic base exchange complexes may be destroyed by ignition at 350° to 400° C without apparently affecting the inorganic exchange material.

3. A large proportion of the exchange capacity of mineral soils is often due to organic matter, ranging from 41 to 65% of the total in the soils studied.

4. The organic matter of different soils differs greatly in its base exchange capacity.

5. Extraction with common organic solvents appears neither to dissolve nor otherwise to affect the base exchange material of soil organic matter.

6. Two fractions of soil organic matter have base exchange properties, namely, the hemicellulose-containing fraction and the "lignin-humus" fraction. The latter fraction is the more important, since it appears to give soil organic matter its more or less permanent base exchange properties. In the peats studied, 60 to 80% of the base exchange capacity was due to this fraction.

7. It is suggested that lignin, or a derivative of very similar nature, is the constituent responsible for the base exchange reactions of the "lignin-humus" fraction of soil organic matter. Supporting this possibility is evidence that there appears to be no relationship between the nitrogen content of the "lignin-humus" fraction and its base exchange capacity, suggesting a nitrogen-free substance as the active constituent; that lignin prepared by a chemical method has base exchange capacity; and that the calcium-magnesium equilibrium constant of the "lignin humus" material is similar to that found for the prepared lignin.

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ORGANIC MATTER CHANGES IN DRY FARMING REGIONS[1]

M. C. SEWELL AND P. L. GAINEY[2]

The maintenance of an adequate supply of organic matter in the soil under dry land farming conditions is very essential from the standpoint of moisture-holding capacity, preserving the crumb structure that resists blowing, and in supplying energy material so essential to the bacterial flora concerned in the fixation of free atmospheric nitrogen.

Because of the difficulties involved in the return of organic materials to the soil and their rapid destruction in regions of low rainfall, the extent of its depletion under various types of farming systems is of particular importance. Also, there is no legume crop well adapted for large-scale dry land farming whereby nitrogen can be returned and the low purchasing power of dry land products at their present exchange value renders the use of commercial nitrogen unprofitable. Hence, any information that may throw light upon

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the carbon and nitrogen balance in semi-arid soils under various farm practises should be of economic as well as scientific value.

Soil nitrogen has not usually been regarded as a limiting factor in crop production under dry farming conditions, but many facts have been brought to light during the past few years that point towards its importance. Examples of these are the common observation in the western third of Kansas that sod lands known to be high in potentially available nitrogen produce "sure" crops; also the influence of nitrogen deposited in urine to which attention has recently been called (1).[3]

The sampling and analyses of soils under various cultural treatments for carbon and nitrogen in 1916 and again in 1928 at three of the western Kansas branch experiment stations furnish information on problems incident to dry land agriculture. The stations are located at Hays, Garden City, and Colby where the annual precipitation is 22.8, 19.0, and 16.5 inches, respectively. Some of these results were briefly presented in connection with a symposium on soil organic matter and green manuring (2), and were partially included in a previous publication concerning the nitrogen balance in cultivated semi-arid western Kansas soils (3). The carbon and nitrogen data for various decidedly contrasting cropping systems at these three stations located in western Kansas are presented in full in 1, 2, and 3.

The Hays data in Table 1 show that both carbon and nitrogen losses were greater in rotations that included an intertilled crop than with continuous wheat culture or with wheat alternating with summer fallow. But among the rotations, the use of peas as a green manure crop, straw, or manure on kafir stubble decreased the loss of nitrogen and carbon. The return of the organic materials, however, did not change the acre yield.

The carbon-nitrogen ratios show a distinct narrowing of the ratio from 1916 to 1928. This narrowing was greater for the rotations including an intertilled crop than for continuous wheat or wheat and fallow.

At Colby, the average rainfall is 6 inches less than at Hays and the elevation is about 3,000 feet compared with 2,000 feet for Hays. The carbon losses at Colby were greater when an intertilled crop was included in the rotation, as at Hays.

The return of straw or manure reduced the amount of carbon loss within the wheat-milo-fallow rotation, while the addition of 12 tons of manure to kafir stubble resulted in a gain.

[3]Reference by number is to "Literature Cited," p. 283.

TABLE 1.—*Carbon and nitrogen losses or gains at Hays, comparing the effect of manure, straw, green manure, rotation, and continuous wheat.*

Plat No.	Treatment	Bushels per acre, ave. 1913–26		Percentage carbon			C, pounds per acre, gain or loss	N:C ratio		Percentage nitrogen			N, pounds per acre gain or loss
		Wheat	Kafir, milo, or corn	1916	1928	Gain or loss		1916	1928	1916	1928	Gain or loss	
54A	Corn, winter wheat, peas,* barley	17.8	5.8	1.59	1.19	—0.40	— 8,000	11.1	9.0	0.143	0.133	—0.010	—200
552B	Wheat, kafir, fallow	23.2	23.2	1.75	1.14	—0.61	—12,200	10.5	9.1	0.167	0.124	—0.043	—860
554A	Wheat, kafir, fallow, 2½ tons straw on wheat	20.2	18.1	1.76	1.16	—0.60	—12,000	10.9	9.0	0.162	0.130	—0.032	—640
555A	Wheat, kafir, fallow, 3 tons manure on kafir stubble	21.6	21.1	1.74	1.46	—0.28	— 5,600	10.2	9.6	0.170	0.152	—0.018	—360
560A	Wheat, kafir, fallow, 12 tons manure on kafir stubble.	21.2	18.6	1.71	1.51	—0.20	— 4,000	10.2	9.4	0.167	0.160	—0.007	—140
MCB	Winter wheat, early fall plowed	14.9	—	1.74	1.47	—0.27	— 5,400	11.2	10.0	0.155	0.149	—0.006	—120
MCC	Winter wheat, alternate cropped and fallowed	23.2	—	1.57	1.51	—0.06	— 1,200	11.6	11.1	0.135	0.136	+0.001	+20
MCD	Winter wheat, alternate cropped and fallowed	23.2	—	1.75	1.64	—0.11	— 2,200	11.3	11.0	0.155	0.148	—0.007	—140

*Green manure.

TABLE 2.—*Carbon and nitrogen losses or gains at Colby, comparing the effect of manure, straw, green manure, rotation, and continuous wheat.*

Plat No.	Treatment	Bushels per acre, ave. 1915–27		Percentage carbon			C, pounds per acre, gain or loss	Percentage nitrogen			N, pounds per acre, gain or loss	N:C ratio	
		Wheat	Milo	1916	1928	Gain or loss		1916	1928	Gain or loss		1916	1928
154A	Canada peas,* milo, fallow, winter wheat	18.7	24.6	1.66	0.92	—0.74	—14,800	0.143	0.107	—0.036	—720	11.6	8.6
552A	Wheat, milo, fallow	21.6	10.5	1.29	0.79	—0.50	—10,000	0.120	0.098	—0.022	—440	10.7	8.0
554A	Wheat, milo, fallow, 2½ tons straw on wheat	23 2	11.5	1.15	0.80	—0.35	— 7,000	0.114	0.103	—0.011	—220	10.0	7.7
555A	Wheat, milo, fallow, 3 tons manure on milo	24 6	13.4	1.23	0.92	—0.31	— 6,200	0.114	0.099	—0.015	—300	10.7	9.3
560A	Wheat, milo, fallow, 12 tons manure on milo	20.0	7.9	1.21	1.28	+0.07	+ 1,400	0.130	0.133	+0.003	+ 60	9.3	9.6
MCB	Winter wheat, early fall plowed	8.2	16.9	1.86	1.47	—0.39	— 7,800	0.152	0.131	—0.021	—420	12.2	11.2
MCC	Winter wheat, alternate cropped and fallowed	15.7	24.6	1.89	1.51	—0.38	— 7,600	0.157	0.120	—0.037	—740	12.0	12.6
MCA	Spring wheat, spring plowed	5.6	—	1.26	0.96	—0.30	— 6,000	0.108	0.110	+0.002	+ 40	11.6	8.7
MCB	Spring wheat, fall plowed	7.4	—	1.30	0.94	—0.36	— 7,200	0.112	0.105	—0.007	—140	11 6	9.0
MCC	Spring wheat, alternate cropped and fallowed	10.9	—	1.39	0.95	—0.44	— 8,800	0.118	0.107	—0.011	—220	11.8	9.0
MCD	Spring wheat, alternate cropped and fallowed	—	—	1.31	1.14	—0.17	— 3,400	0.117	0.116	—0.001	— 20	11.2	9.9

*Green manure.

TABLE 3.—*Carbon and nitrogen losses or gains at Garden City, comparing the effect of manure, straw, green manure, rotation, and continuous wheat.*

Plat No.	Treatment	Bushels per acre, ave. 1914–27		Percentage carbon			C, pounds per acre, gain or loss	Percentage nitrogen			N, pounds per acre, gain or loss	N:C	
		Wheat	Kafir	1916	1928	Gain or loss		1916	1928	Gain or loss		1916	1928
324D	Kafir, fallow, winter wheat, winter wheat	8.9–6.1	12.2	1.08	0.76	—0.32	—6,400	0.099	0.088	—0.011	—220	10.9	8.6
331D	Winter rye,* kafir, fallow, winter wheat, winter wheat	10.3–6.1	14.4	0.96	0.65	—0.31	—6,200	0.090	0.084	—0 006	—120	10.6	7.7
332D	Winter rye,* winter wheat, kafir, fallow, winter wheat	8.6–10.1	13.9	1.01	0.69	—0.32	—6,400	0.093	0.093	0	0	10.8	7.4
MCB	Winter wheat, early fall plowed	4.9	—	1.34	0.94	—0.40	—8,000	0.107	0.105	—0.002	— 40	12.5	9.0
MCC	Winter wheat, alternate cropped and fallowed	8.7	—	1.25	0.76	—0.49	—9,800	0.092	0.095	+0.003	+ 60	13.5	8.0
MCD	Winter wheat, alternate cropped and fallowed	—	—	1.06	0.81	—0.25	—5,000	0.088	0.095	+0.007	+140	12.0	8.5

*Green manure.

The introduction of Canada peas as a green manure crop resulted in a greater carbon loss than the same rotation without them.

Similarly, the Canada peas green manure treatment did not check the loss of nitrogen when compared with the wheat and fallow treatment, the loss actually being greater than for continuous wheat. The Canada peas, it should be noted, usually made little growth in dry seasons and no attention was given the question of inoculation.

The most marked change in the carbon-nitrogen ratio occurred with an intertilled crop in the rotation. The addition of straw or manure within a rotation including an intertilled crop checked the narrowing of the ratio Because of the small growth of the Canada peas, it is doubtful whether the data should be considered representative of the effects of a green manure crop.

The yield data indicate some benefits from the straw and manure treatments within the wheat-milo-fallow rotation.

At Garden City, the rainfall averages about 2.5 inches more than at Colby. The elevation is not so high as at Colby and evaporation is greater. The yield data of Table 3 show considerably lower yieldf for Garden City than for Colby Another very important point to which attention should be called is the very low carbon and nitrogen content of the Garden City soil as compared with Hays and Colby, due in part to the fact that the original carbon and nitrogen content of the virgin soil was lower than at Colby and Hays, as indicated by the data in Table 4.

TABLE 4.—*Nitrogen and carbon content of sod lands in western Kansas, 1929*

Description	Nitrogen %	Carbon %	N:C ratio
Tribune			
Sod sample, 0-7 in	0.147	1.62	11.0
Sod sample, 7-20 in	0.124	----	
Sod sample, 20-36 in	0.086		
Garden City			
Sod sample adjoining Dry Land Project, 0-7 in	0.122	1.26	10.3
Sod sample adjoining Dry Land Project, 7-20 in.	0.091	0.93	
Sod sample adjoining Dry Land Project, 20-36 in.	0.059	1.10	
Hays			
Sod sample adjoining Dry Land Project, 0-7 in.	0.217	2.62	12.1
Sod sample adjoining Dry Land Project, 7-20 in.	0.097	1.04	
Sod sample adjoining Dry Land Project, 20-36 in.	0.049	1.13	
Colby			
Sod sample (1916), 0-7 in	0.182	2.00	11.0
Sod sample, 7-20 in	0.097	1.00	
Sod sample, 20-40 in	0.072	1.08	

As might have been anticipated where the organic content was already very low, the introduction of an intertilled crop did not materially alter the carbon and nitrogen losses. Winter rye as a green manure crop did not influence the carbon loss but did decrease the nitrogen loss. In all cases, the nitrogen losses for the 12-year period were small and in some instances gains are indicated by the data. The smallest losses or gains were in the case of fallow or rye green manure treatments.

However, since the error in sampling for nitrogen determinations may be as great as 200 pounds per acre, it is evident that the various cropping systems at Garden City have had but little, if any, effect upon nitrogen changes. Unfortunately, no samples of the virgin soil were taken before the soil upon which the plats are located was broken. In order to approximate the original carbon and nitrogen contents as accurately as possible, sod samples were taken in the summer of 1929 from the nearest unbroken sod area available. These were analyzed for carbon and nitrogen with the results given in Table 4.

A study of the carbon and nitrogen content of sod land in comparison with cultivated soils shows that large losses of carbon and nitrogen occur when the Buffalo grass sod is first brought under cultivation. Assuming that the carbon and nitrogen content of sod samples taken in 1928 represent the original carbon and nitrogen content of the soil, certain very interesting comparisons can be drawn. Comparing the same cultural treatment at the three substations, i. e., a rotation including an intertilled crop, the following values are obtained:

The cultivated soil at Colby had lost 35% and 34%, respectively, of its carbon and nitrogen prior to 1916. From 1916 to 1928 a further loss of 25% carbon and 12% nitrogen took place. The total loss from sod to 1928, a period of 23 years, was 60% carbon and 46% nitrogen. Similar calculations based upon the same assumption from the Hays data show a carbon loss of 54.5% and a nitrogen loss of 38.6% of which 15.2% carbon and 4.6% nitrogen occurred between 1916 and 1928. The corresponding losses for Garden City were 39.5% carbon and 27.8% nitrogen, 25.3% of the carbon and 9.0% of the nitrogen having disappeared from 1916 to 1928.

At all three points the nitrogen losses on a percentage basis prior to 1916 were approximately equal to the carbon losses, but from 1916 to 1928 in no instance did the percentage nitrogen loss equal one-half that of carbon. This indicates a marked slowing up of nitrogen losses as the total quantity of nitrogen becomes relatively low, a

condition to which attention has been previously called (3) though based on a different study from a different angle.

Measurements of the nitrogen-carbon balance under different cropping systems from the period 1916–28, show that the nitrogen supply has been maintained in continuous wheat culture in some of the comparisons made and that organic carbon losses have been greatly curtailed where straw, manure, and certain green manure treatments have been practised. The yield data show increases in some instances where organic materials have been returned to the soil. No doubt the differences in yield will become greater as time goes on. There certainly was a marked decrease in the nitrogen and carbon losses through the addition of the organic matter. If weather conditions recur such as caused the terrific soil blowing of 1911 with the loss of all surface soil to the depth of plowing, particularly in northwestern Kansas, the soil that has been receiving the additions of organic materials should be less subject to such damage.

Although the data presented show the need of returning organic matter, which in the dry land farming regions of Kansas is largely straw, to the soil, it must be borne in mind that there are certain disadvantages involved unless the straw residue is incorporated in the soil at the proper time and under proper soil condition.

Straw improperly returned to the soil may have a temporary injurious effect upon plant growth due to the fact that the addition of straw and other plant substances rich in available carbon stimulate, markedly, the development of micro-organisms as a result of which available soil nitrogen may be depleted. Micro-organisms require in their metabolism relatively more nitrogen than do higher plants. When an organic material with a relatively high nitrogen content undergoes decomposition, there is an ample quantity of nitrogen set free as ammonia to supply the increased demand resulting from microbial growth stimulated by the energy-supply carbonaceous material. However, when a material such as straw, high in carbon compounds but low in nitrogen, is incorporated in the soil, microbial growth is stimulated, a demand for soluble nitrogen is created, and immediately a competition is set up between the micro-organisms and higher plants for the soluble nitrogen. During this period, unless the soil contains a sufficient quantity of available nitrogen to supply the needs of both contestants, the higher plants will suffer. The duration of such a period will depend upon the ratio of available carbon to available nitrogen.

This period of nitrogen or rather nitrate minimum appears more quickly and extends over a longer period in nitrogen-poor than in

nitrogen-rich soils. The addition of adequate available nitrogen will overcome this harmful result. The possible value of the addition of nitrate nitrogen under semi-arid conditions is very strikingly shown in some data presented by the Washington Experiment Station (4). When prices of wheat justify it, there may be a place for nitrogen fertilizers under modern conditions of harvesting wheat in order to hasten the decomposition of straw residues when straw cannot be added to the soil long enough prior to planting time to avoid the harmful effects resulting from incomplete decomposition.

In a system of summer fallow once in 3 or 4 years for the production of wheat, plowing for the fallow is done in May or early June. At this time moisture conditions are usually favorable for rapid decomposition of straw and the whole summer period is allowed for it. Through the energy furnished by straw there may even be additions of nitrogen by free fixation. But for the second or third crops after fallow, it is essential that any turning under of stubble and straw be done immediately after harvest and the soil packed in order to favor rapid decomposition.

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NITRATE ACCUMULATION UNDER VARIOUS CULTURAL TREATMENTS[1]

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This investigation comprises work with three series of field plats extending over a period of 5 years. The primary objective was to study the relative influence of cultivation, mulch, weed growth, moisture, and aeration upon nitrate accumulation in soil during the period intervening between harvest and seeding of winter wheat.

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The first series of plats was laid out in the summer of 1915 on an Oswego silt loam soil from which a crop of wheat had been harvested. It consisted of 14 plats, 5 by 8 feet in size, in two parallel rows of seven plats each, all plats being separated by alleys 3 feet wide and designated as Nitrification Series A. The plat treatments, together with a summary of results, are given in Table 1, but in several instances additional explanation as to treatment seems advisable.

Plats 1 and 8 were kept dry during the summer period, being protected by a canvas covering which was kept in place during threatening weather and at night The cover was removed from the plats during the day time in clear weather.

Plats 3, 6, 10, and 14 received applications of water by hand sprinkling sufficient to provide a favorable moisture content.

On plats 5, 6, and 12, the stubble and weed growth were removed by scraping the surface with a hoe. Plats 5 and 6 were cultivated after scraping, while plat 12 received no other treatment. The stubble was worked into the surface soil on the cultivated plats and left standing on the uncultivated plat which was not scraped, in which case growth was kept down by hand weeding. Plat 13 was cultivated in two 3-inch sections by removing the surface, cultivating the second 3-inch section, and replacing the surface. Plats 4 and 11 were aerated by pumping air into the soil by means of under surface perforated pipes.

Moisture and nitrate determinations were made each week during the season from July 7 to September 30, 1915, on duplicated samples taken from each plat at depths of 0 to 3 inches, 3 to 6 inches, and 6 to 12 inches.

Following the sampling of September 30, 1915, the plats were prepared for seeding to winter wheat by cultivating 6 inches deep and were seeded early in October. The crop was harvested June 28, 1916, and samples taken for moisture and nitrate determinations. On July 8, 1916, the plats were given the prescribed surface treatments of the preceding season, and sampled weekly thereafter for moisture and nitrates in sections of 0 to 6 inches and 6 to 12 inches, until September 18, 1916. At the time of seeding wheat, October 6, 1916, samples were taken to a depth of 3 feet in foot sections and moisture and nitrate determinations made.

The surface treatments for the season of 1917 began July 27, at which time samples were taken to a depth of 3 feet. Samples were taken regularly throughout the season until October 7. The plats were again seeded to wheat October 9, 1917.

TABLE 1.—*Seasonal moisture and nitrates in surface foot, average of 3 years, 1915, 1916, 1917, series A, and average moisture and total nitrates for a depth of 3 feet at time of seeding wheat.*

Plat No.	Treatment	Seasonal average		At seeding time	
		Moisture %	Nitrates in p.p.m.	Moisture %	Nitrates in p.p.m.
4	Aerated; natural rain; cultivated 6 in	20.5	33.80	21.3	33.8
5	Natural rain; scraped; cultivated 6 in	22.6	33.07	22.2	28.5
13	Natural rain; cultivated in 3 in. sections	22.5	31.38	23.3	23.6
2	Natural rain; cultivated 6 in	21.3	31.03	21.2	31.0
3	Moist; cultivated 6 in	23.7	29.75	23.2	27.3
6	Moist; scraped; cultivated 6 in	24.0	28.39	26.5	32.4
14	Moist, cultivated 3 in	23.4	26.97	21.8	20.6
1	Dry; cultivated 6 in	15.7	25.89	17.7	27.0
7	Natural rain; cultivated 3 in	23.0	25.06	21.8	23.6
12	Natural rain; scraped; uncultivated.	21.3	24.51	21.5	17.9
9	Natural rain; uncultivated.	20.9	20.45	21.3	17.4
11	Natural rain; aerated; uncultivated	20.0	19.83	22.3	20.9
10	Moist; uncultivated	22.4	19.51	16.2	16.2
8	Dry; uncultivated	14.1	17.95	19.6	14.3

TABLE 2.—*Seasonal moisture and nitrates in surface foot, average of 3 years 1916, 1917, 1918, Series B, and moisture and nitrates in a depth of 2 feet at time of seeding wheat, average of the same period of years.*

Plat No.	Treatment	Seasonal average		At seeding time	
		Moisture %	Nitrates in p.p m.	Moisture %	Nitrates in p.p.m.
3	Natural rain; scraped; cultivated 6 in.; material restored to surface	19.4	64.9	20.9	88.9
4	Moist; cultivated 6 in	21.0	57.7	22.1	71.3
8	Natural rain; cultivated 3 in	18.0	57.0	19.6	71.8
2	Natural rain; cultivated 6 in	19.2	56.0	19.1	76.6
1	Dry; cultivated 6 in	11.9	52.7	10.1	69.5
6	Natural rain; uncultivated	17.9	44.5	18.7	62.2
5	Dry; uncultivated	11.6	42.8	10.5	68.7
7	Natural rain; scraped; cultivated	17.2	42.5	18.1	61.5

In July, 1916, work along similar lines was begun on a second series of plats on the same soil type and located near Series A.

These plats, eight in number and 8 by 12 feet in size, were designated as Nitrification Series B. The various tillage treatments and the average moisture and nitrate content of soil are given in Table 2.

The data in Tables 1 and 2 are arranged in order of magnitude of average nitrate content of the surface foot for the season, the values being the average of 3 years.

Again all plats were kept free of weeds by hand weeding. Moisture and nitrate determinations were made weekly from July 21 to September 22, 1916, on samples from each plat in sections 0 to 6 inches and 6 to 12 inches and on October 4, the last sampling prior to seeding wheat, to a depth of 3 feet in foot sections.

The cultural treatments of the 1917 season began July 26, at which time all plats were again prepared as in 1916. Samples were taken to a depth of 3 feet at the beginning of the season July 25, and the final sampling in the fall, October 4, and at weekly intervals between these dates in sections 0 to 6 inches, 6 to 12 inches, and 12 inches to 2 feet deep.

Wheat planted on plats in the fall of 1917 was harvested June 24, 1918. The first soil samples of the 1918 season were taken July 19. The plats received their respective tillage treatments July 20, 1918. Soil samples for the determination of moisture and nitric nitrogen were taken approximately every 2 weeks during the season up to September 14.

A third series of plats known as the Soil Mulch Project was started in 1914. On this latter project three different surface treatments of the soil were maintained for 5 years. The treatments were as follows: Weeds allowed to grow; soil cultivated 3 inches deep; and soil kept bare, not cultivated. Summarized nitrate data from the soil mulch work are presented in Table 3.

TABLE 3.—*Average seasonal nitrates as p. p. m. in upper 3 feet of soil.*

Year	Soil treatments		
	Weeds allowed to grow	Cultivated 3 in.	Bare surface uncultivated
1914	32.2	129.1	184.9
1915	10.9	128.6	166.8
1916	20.4	63.9	81.3
1917	22.2	56.8	57.1
1918	0.0	35.4	41.1
Average	17.1	82.7	106.2

In Table 4, are presented the precipitation data for the seasons 1914 to 1917, inclusive.

TABLE 4.—*Precipitation by months from July to September, 1914–17, inclusive.*

Month	Rainfall in inches			
	1914	1915	1916	1917
July	1.1	15.0	2.3	0.5
Aug	2.7	2.2	0.2	6.2
Sept	4.3	4.7	7.3	1.5

DISCUSSION

The data presented in Tables 1 and 2 possibly do not show as marked differences resulting from the various treatments as one might expect. However, certain rather significant points are indicated, one of which is the marked accumulation of nitrate nitrogen in the dry plats where the moisture content was relatively low, varying from 11.6 to 15.7%. This would indicate that under relatively dry climatic conditions sufficient nitrates may be formed for crop production provided there is an ample supply of raw material for the nitrifying organisms to work with, and the removal of nitrates by weeds is prevented by adequate cultivation.

Another point worthy of note is the influence of cultivation upon the accumulation of nitrates during the interval between harvest and seeding. This is not so evident as the data are presented in Table 1; but when the similarly treated cultivated plats are contrasted with the unworked, the influence of cultivation is very evident, as the following comparison taken from Table 1 will show:

	Seasonal		Seeding time	
	Moisture %	Nitrates, p.p.m.	Moisture %	Nitrates, p.p.m.
Cultivated 6 in., ave. 5 plats	20.8	30.71	21.1	29.52
Cultivated 3 in., ave. 2 plats	23.2	26.01	21.8	22.10
Uncultivated, ave. 5 plats	19.7	20.46	20.2	17.30

There are some indications that moisture and not cultivation may be the controlling factor, but the number of exceptions to such a correlation exhibited in both Tables 1 and 2 indicate that cultivation has been a more dominant factor than the variation in moisture content induced by the various treatments, excepting of course the two dry plats.

A similar comparison of plats 2, 3, and 6 and 1 and 5 of Table 2, wherein cultivation is contrasted with an uncultivated condition, show similar effects upon nitrate accumulation in both instances.

The effect of removing the stubble and weed growth by scraping upon the nitrate content was negligible, as indicated in the following comparisons taken from Table 1:

	Seasonal		Seeding time	
	Moisture %	Nitrates, p.p.m.	Moisture %	Nitrates, p.p.m.
Unscraped, cultivated 6 in..	21.3	37.07	21.2	28.5
Scraped, cultivated 6 in. .	22.6	31.03	22.2	31.0
Unscraped, uncultivated...	20.9	20.45	21.3	17.4
Scraped, uncultivated .. .	21.3	24.51	21.5	17.9
Unscraped, moist, cultivated	23.7	29.75	23.2	27.3
Scraped, moist, cultivated.	24.0	28.39	26.5	32.4

This conclusion, drawn from the data of Series A, is substantiated by the following comparison taken from Table 2, Series B:

	Seasonal		Seeding time	
	Moisture %	Nitrates, p.p.m.	Moisture %	Nitrates, p.p.m
Unscraped, uncultivated...	17.9	44.5	18 7	62.2
Scraped, uncultivated .	17.2	42.5	18.1	61.5

Similarly, the forcing of air into the soil had but very little, if any, influence upon nitrification as the following comparisons indicate:

	Seasonal		Seeding time	
	Moisture %	Nitrates, p.p.m.	Moisture %	Nitrates, p.p.m.
Aerated, cultivated 6 in....	20.5	33.80	21.3	33.8
Unaerated, cultivated 6 in..	21.3	31.03	21.2	31.0
Aerated, uncultivated.....	20.0	19.83	22.3	20 9
Unaerated, uncultivated...	20.9	20 45	21.3	17.0

The addition of moisture in excess of natural precipitation was without effect upon nitrate accumulation, as the following comparison, an average of three plats of Series A receiving similar treatments except for the addition of moisture, will show:

	Seasonal		Seeding time	
	Moisture %	Nitrates, p.p.m.	Moisture %	Nitrates, p.p.m.
Natural rain plus moisture.	23.7	28.37	23.8	26.77
Natural rain	22.3	29.72	21.7	27.70

A similar comparison of plat 2 (natural rain, cultivated) with plat 4 (natural rain plus moisture, cultivated) of Series B reveals similar results. These results, also, indicate very strongly that moisture was probably not the controlling factor in nitrate accumulation if the moisture content were in excess of 20%.

A comparison of the results secured from the mulch series with those of the nitrification series reveals one marked discrepancy, namely, the effect of cultivation upon nitrate accumulation. This is particularly difficult to explain in view of the fact that all three series of plats were under investigation at the same time. However, they were not located on the same area though the soil was of the same type. There is the possibility that the previous treatment of the soil before the location of the plats may have in some way altered the effect of cultivation. Also, the results secured from Series A indicate that the effect of cultivating 3 inches deep is much less than cultivating 6 inches, and in the mulch series the soil was worked only to a depth of 3 inches.

Aside from the failure of cultivation to stimulate nitrate accumulation in the mulch series, the effect of the different factors studied was remarkably similar in the three series. Even though cultivation resulted in a more marked accumulation of nitrates, the indications are that during a short period of time, such as the 3 years in these experiments, ample accumulation of nitrates will take place in an uncultivated soil to insure sufficient nitrates for excellent growth of wheat, provided weed growth is prevented. In the seedbed preparation project[3] covering a period of 10 years, the highest yield was produced where there was an average nitrate content of 27.6 p. p. m. at seeding time. The average nitrate contents in the uncultivated plats of Series A and B were 20.4 and 43.6 p. p. m., respectively.

The stubble worked into the soil on these plats represented the stubble left by the wheat binder. During the short period under study its removal by scraping did not affect the accumulation of nitrates. However, continuous removal of the stubble would undoubtedly result in a decrease in total nitrogen, a decrease in food for nitrogen-fixing organisms, poor physical condition, etc. On the other hand, with the introduction of modern combining methods where all the straw is returned to the soil, the introduction of very large amounts of such highly carbonaceous material as accompany a very heavy harvest will undoubtedly introduce new carbon-nitrogen relationships which may result in a temporary retardation in nitrate accumulation. There is an urgent need for investigations along these lines and one of the objects in presenting these data at this late date is the hope that it may stimulate further study of some of the problems involved in the changing agricultural conditions in the great hard winter wheat belt.

[3]Sewell, M. C., and Call, L. E. Tillage investigations relating to wheat production. Kan. Agr. Exp. Sta. Tech. Bul. 18. 1925.

STUDIES ON THE BREAKING STRENGTH OF STRAW OF OAT VARIETIES AT ABERDEEN, IDAHO[1]

L. L. Davis and T. R. Stanton[2]

Reliable observations on straw strength in oats are very difficult to make under field conditions. The chief advantage of a satisfactory mechanical straw test would be to supplement field observations. However, some other advantages may be conceived for the mechanical straw-breaking test. The testing of oat hybrids for straw strength where the quantity of material is small may be very advantageous. Relative straw-breaking strength can be determined each season regardless of the conditions, as in certain localities and under certain conditions lodging in the field may be impossible to induce.

Only very meager results have been reported on the mechanical testing of relative straw strength in small grain varieties. Willis (6)[3] has indicated that stiffness of straw is one of the important factors to be considered in varietal testing and breeding work with the small grains. He describes the apparatus and gives instructions for operating it, but he presents no results of straw-breaking studies on strains or varieties of oats or other small grains.

Helmick (1) describes an apparatus for determining the breaking strength of straw. He presents data on the frequency distribution for variation in the relative breaking strength of straw for Turkey and Red Wave wheats grown under the environment of Ithaca, N. Y. The results obtained show that the variability in breaking strength is about the same for the two varieties. However, a varietal difference with respect to strength of straw is indicated.

Results obtained from studies on the relative breaking strength of straw of oat varieties grown under irrigation at the Aberdeen Substation, Aberdeen, Idaho, in 1929 and 1930, are reported in this paper.

[1]Results of cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Idaho Agricultural Experiment Station. Received for publication August 4, 1931.

[2]Formerly Junior Agronomist in charge of cereal investigations, Aberdeen Substation, Aberdeen, Idaho, now Assistant Agronomist in charge of rice investigations and Superintendent of the Rice Field Station, Biggs, Calif.; and Senior Agronomist in charge of Oat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3]Reference by number is to "Literature Cited," p. 300.

MATERIALS AND METHODS

Experiments were made on the breaking strength of straw of the registered improved and standard varieties of oats grown in the cereal improvement nursery at Aberdeen. These two lots of material were represented by 32 and 41 varieties, respectively, in 1929, and by 35 and 36 varieties in 1930. A few of the improved registered varieties also were included in the so-called standard group of varieties.

Information on the origin, development, performance, and description of the registered improved varieties has been published by Stanton, *et al.* (2, 3, 4, 5). The standard varieties included midseason white and midseason yellow oats, constituting those believed to be worthy of testing for yield under irrigation at Aberdeen. Some of the newer and better Canadian varieties were included in the standard lot.

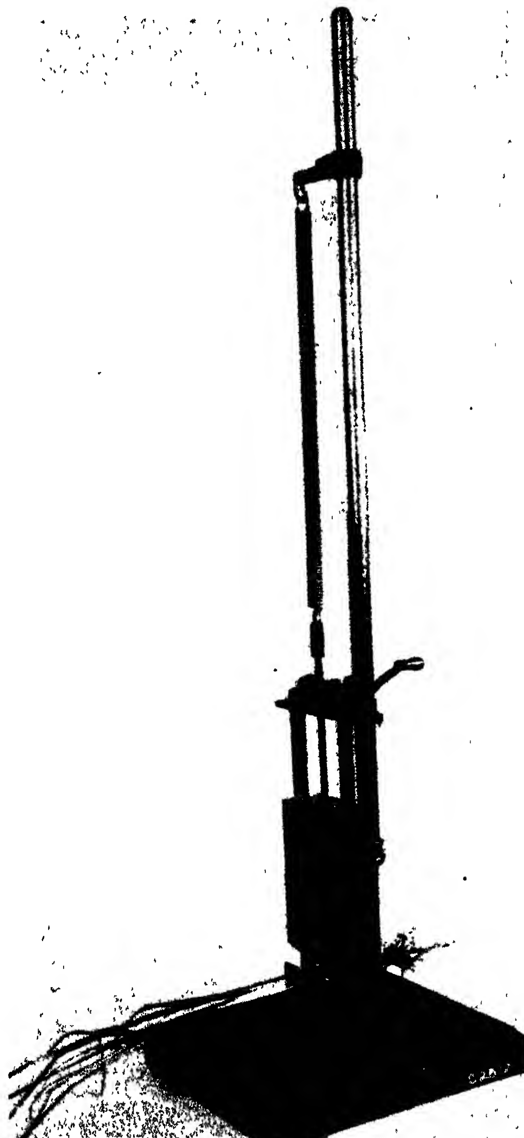

FIG. 1.—Machine used to determine breaking strength of straw of oat varieties.

The registered improved varieties were grown in 6-foot

rows in 1929. The seeding rate was approximately 1 gram per foot. When the varieties were about ripe, notes were made on the width of the second leaf from the top, length of culm, and length of panicle.

The weight of the straws that were broken was determined at the time of the straw-breaking test. When the varieties were ripe each was harvested with a sickle, the straws being cut off even with the surface of the ground. The straws from each variety were then tied securely, care being taken not to crush the straw. The bundles were stored in the seed room, and the straw-breaking test was made about 5 weeks later

The registered improved varieties were grown in single rod rows in 1930. The seeding rate was 15 grams per row. When the varieties were ripe a 5-foot portion was harvested from each row. The samples were handled in the same manner as in 1929. As additional notes to those taken in 1929, determinations were made on the weight of grain and weight of panicles from the 100 culms used in the breaking tests.

The straw of the standard varieties grown in replicated 3-row blocks was taken from one of the guard rows after the center row had been harvested for yield of grain. The straw was harvested and stored in the same manner as the straw from the registered varieties. In all cases care was taken not to use straws from the end of the row where border effect would influence size of the straw.

The straw-breaking tests were made on a machine (Fig. 1.) designed by Prof. S. C. Salmon, formerly of the Kansas State Agricultural College, but now of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.[4] The machine was built by the engineering department of the Kansas State Agricultural College. The straw breaking is accomplished by gradually lowering a weight supported by a coil spring. The readings are made on a bar calibrated in centimeters. By attaching scales to the machine and recording the pounds developed at each centimeter, it is possible to convert the centimeter reading into pounds.

Five straws were broken in the machine for each breaking trial. Ten or 20 determinations were made for each variety, depending on the quantity of good, uniform material available. This makes a total of 50 or 100 straws broken for each variety. The straws were broken between the first and second nodes from the base.

[4]Since this paper was prepared an article containing a complete description of this machine has been published as follows:

SALMON, S. C. An instrument for determining the breaking strength of straw and a preliminary report on the relation between breaking strength and lodging. Jour. Agr. Res., 43: 73-82. 1931.

EXPERIMENTAL DATA

REGISTERED IMPROVED VARIETIES

Results in 1929

A summary of the various data recorded on the registered improved varieties grown in the season of 1929 is shown in Table 1. The varieties are listed in the order of their straw-breaking strength. The purpose of measuring numerous plant characters was to make a study of their relationship to straw-breaking strength. Each plant character measurement is an average of 10 determinations.

TABLE 1.—*Data recorded on the registered improved oat varieties grown at the Aberdeen Substation, Aberdeen, Idaho, 1929.*

Variety	C. I. No.*	Reg. No.†	Average of 10 measurements			Total weight of the 50 straws broken, grams	Ave. of 10 breaking tests and probable error, lbs.
			Width of 2nd leaf, mm	Length of culm (minus panicle), cm	Length of panicle, cm		
Iogren	2024	51	15.1	78.3	27.8	87	7.45±0.132
Empire	1974	55	15.8	74.5	22.9	80	7.45±0.090
Wisconsin Wonder	1645	62	17.2	86.0	27.2	94	7.45±0.125
Wolverine	1591	70	16.6	88.1	24.4	77	7.45±0.094
Colorado No. 37	1640	53	18.3	72.8	24.3	88	7.04±0.135
Wayne	2567	77	17.0	78.8	23.1	81	7.04±0.119
Comewell	1317	54	16.4	73.5	23.9	82	6.99±0.168
Ithacan	2141	58	16.9	75.7	24.9	79	6.94±0.152
Markton	2053	52	14.9	71.9	26.6	72	6.90±0.117
Worthy	1590	71	16.6	85.6	25.5	94	6.86±0.194
Keystone	2146	68	14.2	83.4	25.8	78	6.81±0.133
Patterson	2147	69	14.5	88.1	26.6	82	6.81±0.127
Standwell	1975	60	17.2	82.2	24.6	80	6.59±0.162
Miami	2245	76	16.2	86.9	21.7	87	6.59±0.159
Upright	2142	61	16.1	78.7	25.4	74	6.54±0.145
Tech	947	63	12.6	66.9	24.7	62	6.54±0.107
Forward	2242	56	14.8	74.4	23.5	73	6.27±0.115
White Cross	2026	49	15.0	85.2	24.6	86	6.23±0.189
Idamine	1834	57	16.0	82.4	23.0	73	6.05±0.135
State Pride	1154	45	12.2	77.1	22.6	66	5.87±0.114
Gopher	2027	47	15.8	76.0	21.3	73	5.64±0.147
Nortex	2382	67	11.1	78.8	18.2	59	5.64±0.059
Cornellian	1242	50	15.7	89.4	25.7	82	5.59±0.095
Iowar	847	48	13.5	69.1	22.3	57	5.50±0.090
Albion	729	46	12.0	72.1	20.7	56	5.41±0.068
Minota	1285	59	13.6	69.9	20.9	60	5.41±0.150
Iogold	2329	72	13.4	63.3	20.4	54	5.41±0.087
Richland	787	44	11.8	68.5	18.6	50	5.37±0.142
Colburt	2019	43	13.1	75.7	20.3	56	5.18±0.085
Lee	2042	64	11.5	85.5	24.6	64	5.18±0.091
Kanota	839	66	11.9	71.7	17.8	50	5.13±0.110
Frazier	2381	65	11.3	63.6	18.1	41	4.36±0.094

*Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

†Registration number of the American Society of Agronomy and the Bureau of Plant Industry.

The relationship between the various plant characters and straw-breaking strength has been determined by calculating correlation coefficients.

The results of correlating straw-breaking strength with certain plant characters are given in Table 2. The value of the correlation coefficients on only 32 varieties may be questioned. However, the coefficients are statistically significant, as is indicated by their probable errors.

The highest correlation coefficient obtained was $+ .841 \pm .035$, this being between the straw-breaking strength and the weight of the 50 straws broken. The lowest correlation coefficient value of $+ .450 \pm .095$ was obtained between the straw-breaking strength and height of culm.

TABLE 2.—*Correlation coefficients between the breaking strength of straw and other plant characters in 32 registered improved oat varieties grown at the Aberdeen Substation, Aberdeen, Idaho, in 1929.*

Characters correlated with breaking strength of straw	Correlation coefficient and probable error
Width of the second leaf	$+.785 \pm .045$
Height of the culm (minus panicle)	$+.450 \pm .095$
Length of the panicles	$+.736 \pm .055$
Weight of the 50 straws broken	$+.841 \pm .035$

On the basis of the results obtained in 1929, it was evident that the registered improved varieties differed considerably in relative strength of straw when grown under the environment of Aberdeen, Idaho. The midseason common varieties as a group apparently have much stronger straw than the early common and early red-oat varieties. There are important differences, however, in the breaking strength of straw within these varietal groups that will be discussed later.

Results in 1930

A summary of the data obtained from the study of plant characters and straw-breaking strength of the registered improved varieties grown in 1930 are given in Table 3.

The varieties are listed in the order of their straw-breaking strength. There was a wider range in the breaking strength of straw for the varieties grown in 1930 than in 1929. Colorado No. 37 (C. I. No. 1640) has the highest straw-breaking reading—an average of 7.78 pounds—and Brunker (C. I. No. 2054) has the lowest average straw-breaking reading, 2.75 pounds.

As in 1929, a high degree of association was found between straw-breaking strength and the various plant characters studied. The correlation coefficients for the varieties grown in 1930 are given in

TABLE 3.—*Data recorded on the registered improved oat varieties grown at the Aberdeen Substation, Aberdeen, Idaho, in 1930.*

Variety	C. I. No.	Reg. No.	Weight of 100 panicles, grams	Weight of grain from 100 panicles, grams	Weight of 100 straws broken, grams	Average of 10 measurements: Width of second leaf mm	Average of 10 measurements: Length of culm (minus panicle), cm	Average of 10 measurements: Length of panicle, cm	Average of 20 breaking tests and probable error, lbs.
Colorado No. 37	1640	53	218	171	222	11.4	125.0	21.5	7.78±0.094
Ithacan	2141	58	191	143	198	11.4	116.3	21.4	7.27±0.099
Standwell	1975	60	195	136	207	12.0	124.4	23.2	7.22±0.083
Wisconsin Wonder	1645	62	185	149	206	12.4	117.3	23.2	7.13±0.109
Anthony	2143	75	144	110	173	11.8	111.6	20.5	6.99±0.111
Worthy	1590	71	179	125	182	11.5	111.4	20.5	6.94±0.085
Forward	2242	56	204	159	204	13.0	120.6	21.7	6.90±0.111
Upright	2142	61	222	147	205	11.1	117.6	22.6	6.81±0.128
Wolverine	1591	70	175	134	161	11.2	118.8	21.6	6.81±0.085
Empire	1974	55	173	134	177	12.2	122.4	21.2	6.81±0.072
Wayne	2567	77	167	133	175	11.5	111.8	19.5	6.77±0.081
Iogren	2024	51	166	128	185	10.1	118.1	23.3	6.68±0.068
Comewell	1317	54	174	137	187	11.7	117.3	20.7	6.45±0.090
Idamine	1834	57	168	132	182	11.8	121.9	21.6	6.41±0.074
Miami	2245	76	165	135	174	11.7	113.0	19.2	6.14±0.080
Keystone	2146	68	128	100	151	9.9	106.8	21.8	5.87±0.071
Patterson	2147	69	129	109	166	10.1	109.3	21.3	5.59±0.045
Cornellian	1242	50	157	122	175	9.7	113.5	22.5	5.46±0.053
White Cross	2026	49	161	126	164	10.3	105.2	22.2	5.37±0.075
Markton	2053	52	158	115	162	10.4	107 0	26.0	5.28±0.080
Tech	947	63	107	65	131	11.1	93.2	23.9	5.13±0.065
Gopher	2027	47	157	126	144	11.0	104.9	19.1	4.95±0.066
Iowar	847	48	147	118	132	9.9	108.9	20.5	4.71±0.036
State Pride	1154	45	129	103	135	9.4	112.6	21.1	4.52±0.074
Minota	1285	59	136	106	146	9.6	111.8	19.2	4.32±0.048
Rainbow	2345	74	129	95	115	9.5	98.0	19.2	4.16±0.041
Kanota	839	66	122	103	114	9.7	104.2	18.3	3.94±0.042
Frazier	2381	65	135	115	100	9.1	94.9	17.9	3.72±0.047
Colburt	2019	43	117	95	115	11.1	104.8	20.1	3.44±0.030
Albion	729	46	105	78	101	8.4	101.1	20.0	3.39±0.032
Nortex	2382	67	86	70	94	7.5	95.2	16.9	3.03±0.024
Iogold	2329	72	106	80	85	9.6	84.2	17.4	3.03±0.033
Richland	787	44	116	96	98	10.0	95.6	19.0	2.98±0.030
Lee	2042	64	69	45	108	9.2	103.0	27.0	2.93±0.032
Brunker	2054	73	78	59	75	8.8	92.4	15.8	2.75±0.035

Table 4. Five of the six correlation coefficient values are statistically significant. The value of + .371 ± .098 between the straw-breaking strength and the length of panicle is not statistically significant. The highest correlation coefficient was + .946 ± .012, that is, between the breaking strength and the weight of the 100 straws broken.

There was close agreement between the results for 1929 and 1930 on straw-breaking strength as determined by the straw-breaking machine. The correlation coefficient calculated on the basis of a double frequency distribution of the 1929 and 1930 straw-breaking readings is + .863 ± .030.

TABLE 4.—*Correlation coefficients between breaking strength of straw and other plant characters in 35 registered improved oat varieties grown at the Aberdeen Substation, Aberdeen, Idaho, in 1930.*

Characters correlated with breaking strength of straw	Correlation coefficient and probable error
Weight of 100 panicles	+.872±.027
Weight of grain from 100 panicles	+.684±.061
Weight of the 100 straws broken	+.946±.012
Width of the second leaf	+.770±.046
Height of the culm (minus panicle)	+.836±.034
Length of the panicles	+.371±.098

STANDARD VARIETIES

The straw-breaking results on the so-called standard varieties grown at Aberdeen in 1929 and 1930, respectively, are given in Table 5. These varieties are listed in the order of their breaking strength for each year.

The varieties grown in the yield-test nursery at the Aberdeen Substation are of similar type, that is, all are midseason in maturity with straw of about the same height and diameter Therefore, there was not as great a range in the readings of the breaking-strength in these as in the registered improved varieties. The variety Silver (C. I. No. 2269) has the highest average breaking strength of straw. The readings were 7.69 pounds in 1929 and 8.67 pounds in 1930. Rainbow (C. I. No. 2345) had the lowest average straw-breaking reading, 3.66 pounds in 1929 and 4.57 pounds in 1930.

The correlation coefficient between the straw-breaking results obtained in 1929 and 1930 was calculated. A correlation value of + .702 ± .057 was obtained. This value is statistically significant, but not so high as the correlation coefficient obtained between the 2-year results on the registered improved varieties.

DISCUSSION

It is obvious that many factors may influence the results of a study of straw strength in oat varieties. Such factors as evenness of stand

may greatly influence the size of the straw and consequently the breaking strength. Obtaining samples at the proper time, that is, when each variety is at the same stage of maturity, is very difficult. As a consequence, lack of uniformity in harvesting may influence the straw-breaking strength. There is the question of whether the breaking strength of the straw after it has been thoroughly dried is in

TABLE 5.—*Data recorded on the breaking strength of straw of standard oat varieties grown in the replicated rod-row nurseries at the Aberdeen Substation, Aberdeen, Idaho, 1929 and 1930.*

1929

Variety	C. I. No.	Av. of 20 breaking tests and probable error,* lbs.
Silver	2269	7.69±0.067
Grey Moore	2237	7.45±0.095
Hatvan	2117	7.41±0.081
Silver (Abed)	2206	7.32±0.095
Grey Moore	2472	7.13±0.104
Ohio No. 201	2477	6.94±0.105
Columbian	2470	6.90±0.079
Victory	2020	6.72±0.128
Gerlach	2244	6.72±0.098
Victory	1991	6.54±0.086
Victory	1279	6.45±0.126
Vietto	2010	6.36±0.094
Gerlach	2471	6.36±0.112
Triumph No. 20	1793	6.32±0.113
Golden Rain	1718	6.32±0.086
Wasa	1984	6.32±0.119
King	2473	6.32±0.081
Fortuna	1983	6.27±0.109
Siberian	846	6.18±0.092
Golden Rain	2004	6.18±0.107
Swedish Select	1627	5.96±0.069
Abundance	2038	5.91±0.072
Belyak	1899	5.91±0.086
Andrew	2469	5.68±0.080
Victory	2037	5.64±0.095
Idamine	1834	5.59±0.064
Prolific	2479	5.59±0.088
Echo	1982	5.50±0.087
Crown	2022	5.46±0.070
Golden Rain	1890	5.46±0.100
Golden	1750	5.41±0.056
Anthony	2043	5.41±0.084
Standwell	1975	5.28±0.084
O. A. C. No. 144	2235	5.13±0.064
Golden Rain	1988	5.09±0.090
Banner (Improved)	1997	4.76±0.079
Iowa No. 444	2331	4.47±0.067
Progress	2478	4.47±0.074
Mansholt, No. III	2046	4.05±0.053
Markton	2053	3.99±0.053
Rainbow	2345	3.66±0.041

*Twenty determinations were made on each variety, using five straws for each determination.

TABLE 5.—*Continued.*

1930

Variety	C. I. No.	Av. of 10 breaking tests and probable error,† lbs.
Silver	2269	8.67±0.037
Hatvan	2117	8.67±0.040
O. A. C. No. 144	2235	8.67±0.036
Grey Moore	2237	8.62±0.072
Victory	1991	8.23±0.112
Silver (Abed)	2206	8.18±0.133
Triumph No. 20	1793	8.18±0.069
Grey Moore	2472	8.13±0.096
Siberian	846	8.13±0.089
Belyak	1899	8.13±0.148
Vietto	2010	8.03±0.091
Abundance	2038	8.03±0.095
Ohio No. 201	2477	7.98±0.087
Victory	1279	7.98±0.093
Victory	2020	7.93±0.096
Fortuna	1983	7.93±0.129
Golden Rain	1988	7.83±0.121
Victory	2037	7.78±0.123
Standwell	1975	7.69±0.122
Columbian	2470	7.64±0.184
Banner (Improved)	1997	7.64±0.105
Wasa	1984	7.59±0.099
Idamine	1834	7.41±0.158
Crown	2022	7.41±0.137
Andrew	2469	7.36±0.138
Golden	1750	7.13±0.123
Prolific	2479	7.09±0.121
Echo	1982	7.09±0.137
Gerlach	2244	7.04±0.078
Swedish Select	1627	6.94±0.136
Golden Rain	1718	6.94±0.126
Gerlach	2471	6.41±0.108
Progress	2478	6.14±0.136
Markton	2053	6.09±0.076
Mansholt No. III	2046	5.59±0.102
Rainbow	2345	4.57±0.061

†Ten determinations were made on each variety, using five straws for each determination.

direct relation to the strength of the straw when lodging normally occurs in the field. Climatic factors, such as humidity and temperature at the time the straw-breaking tests are made, may influence the breaking strength.

Some of the varieties studied and found to have weak straw as determined by a mechanical test under the environment of Aberdeen may show higher breaking strength of straw when grown in other regions. On the other hand, the larger-strawed, midseason common varieties which show high breaking strength of straw under the conditions at Aberdeen may show lower breaking strength of straw when

grown under conditions less favorable for oats, that is, primarily in the range of the early common and early red varieties.

As a result, the straw-breaking data presented in this paper are applicable perhaps only to conditions similar to those found at Aberdeen, Idaho, and for the two seasons, 1929 and 1930.

Observations on resistance to lodging in the field agree with the results of the straw-breaking tests for most of the varieties reported upon in this paper. Several of the reputed stiff-strawed sorts, such as Wisconsin Wonder, Wolverine, Colorado No. 37, Wayne, Ithacan, Worthy, Standwell, and Upright, were among the first 15 varieties in relative straw-breaking strength in 1929. However, among the first 15 there also were the more slender and somewhat weaker-strawed sorts, such as Iogren, Markton, Keystone, and Patterson.

The early, slender-strawed varieties, such as Iowar, Albion, Iogold, and Richland, under the conditions at Aberdeen rank low in straw-breaking strength. The southern red-oat varieties, Brunker, Frazier, Kanota, and Nortex, which are far removed from their proper range when grown at Aberdeen, also rank low in relative straw-breaking strength.

The results obtained in 1930 on the registered improved varieties agree much better with general observations on relative standing ability. The first 10 varieties in relative straw-breaking strength include some of the stiffest-strawed varieties that have been developed in the United States. The early common and early red varieties were the lowest in straw-breaking strength, as they were in 1929. These results indicate rather definitely that there is considerable correlation between observations made in the field and the results of a mechanical straw-breaking test.

SUMMARY

There are several advantages of a satisfactory mechanical straw-breaking test for determining straw strength of oats. Its chief advantage is that it can be used where lodging of the grain does not occur. Other advantages are that it can be used to supplement observations on field lodging and to test hybrids where the quantity of material is limited.

Data obtained from the straw-breaking tests at Aberdeen on the registered improved varieties clearly separate the midseason from the early varieties. Under the almost ideal conditions for oats found under irrigation in southern Idaho, the midseason and larger-strawed varieties undoubtedly develop the stronger straw.

Significant correlations were found to exist between the breaking strength of straw and several plant characters, such as weight of

panicles, weight of grain, weight of straws broken, height of culm and width of second leaf.

A correlation coefficient of + .863 ± .030 was obtained between the breaking strength of straw of 32 registered improved varieties for the years 1929 and 1930.

There was close agreement between the breaking strength of straw of standard varieties grown in the regular yield test nursery of 1929 and 1930. A correlation coefficient value of + .702 ± .057 was obtained. The range in the breaking-strength readings for these varieties was not so great as that for the registered improved varieties. This is due primarily to the fact that the standard varieties are all of the midseason type with straw of similar height and diameter.

In general, the reputed stiff-strawed varieties as determined by field observations when subjected to a mechanical straw strength test, showed the highest resistance to breaking.

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THE PHYSIOLOGICAL BEHAVIOR OF REGIONAL STRAINS OF POTATOES[1]

JOHN JACOB PIEPER[2]

That northern-grown seed potatoes are more productive than southern home-grown seed, especially when planted where the climatic environment is not as generally favorable for potatoes as that of the northern regions, has been well established. The reason for the unproductivity of southern seed potatoes has not been fully

[1]Contribution from the Departments of Agronomy and Botany, University of Wisconsin, Madison, Wis., and the Departments of Agronomy and Botany, University of Illinois, Urbana, Ill. Submitted in partial fulfillment of the requirements for the degree of doctor of philosophy, University of Wisconsin. Received for publication December 19, 1931.

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ascertained. The main object of the experiments reported in this paper was to study the physiological behavior of several regional strains of potatoes.

REVIEW OF LITERATURE

The number of eyes per seed piece, as recorded by Aicher (1),[3] greatly influences the number of stalks per set. According to the Rhode Island Experiment Station (10), large seed pieces of only two eyes, the remainder having been dug out, gave more stalks than a small seed piece of two eyes. This thicker stand increased the yield, but where all hills were thinned to an equal number of stalks, the yield was about the same. Yield, therefore, was not influenced by the larger seed piece if all were thinned to the same number of stalks per hill

Rosa (11), Clark (6, 7), Aicher (2), and Stuart (13) have shown that the number of stalks increases with the size of the seed piece. According to Aicher (1) and Welch (14), the smaller sets, regardless of method of cutting, gave the smallest number of stems, while the quartered tubers, regardless of the size, produced the fewest shoots. Stewart (12) presents experimental evidence to show that small whole tubers sent up an average of 1.91 stalks per hill, while cut seed of nearly equal weight, from the same plant, gave 2.14 stems per hill. Stem-end sets produced 2.40 stems, seed ends 2.09, and the middle portion with only one eye, 1.95 stems. Appleman (3) says that most varieties under normal conditions will not produce enough stalks from any size seed piece to cause serious crowding.

The lowest average number of stalks (1.43 stems) per hill, according to Rosa (11), is obtained with home-grown tubers produced during the autumn months. Spring-grown tubers produced 3.44 stems per hill and northern-grown potatoes, 2.10 stems per hill. "The difference in the number of stalks per hill is so pronounced and so consistent that the other hill and tuber characteristics noted seem to be largely, if not entirely, the direct result of them."

Jones and his co-workers (8) show that the number of stems per hill increases from 2.8 per set at 11° to 12°C to 4.6 stems per set at 21.0° to 21.5° C, and then decreases to 2.8 stems per set at 27.0° to 30.5°C.

They also show that the tallest plants occur when grown at 28°C, and the greatest diameter of plants at 15°C. The greatest amount of green top growth was produced at 21°C. Whole tubers, according to Aicher (1), produced the largest and most vigorous stems.

Aicher (1) and Welch (14) show that not only do the shoots from

[3]Reference by number is to "Literature Cited," p. 311.

the largest seed pieces emerge first, but that shoots from whole sets emerge first, with halves next and quartered sets last.

Auxiliary branches develop at high temperatures, according to Jones (8). Bushnell (4) used temperatures ranging from 20° to 29°C, and speaks of branches having been produced under cool temperatures.

Moore (9) says, "It should be remembered that the number of potatoes a hill produces is determined largely by the number of stems in a hill. A productive single-stem hill should produce four or more good tubers. A hill of two or more stems may produce six or more pototoes and yet not have as good yielding qualities as the one-stem hill that grows four tubers." According to Stewart (12), two stalks per hill yielded better than three stalks per hill. Bushnell (5) admits that field data relative to the time of planting potatoes are difficult of interpretation because of the variations in the number of stems per hill for the various dates of planting.

Stuart (13), Rosa (11), and Aicher (1) show that there is a very close correlation between the number of stems and the percentage of marketable tubers. A large number of stems gives a low percentage of marketable potatoes. According to Rosa (11), the best yields and the lowest percentage of culls accompanies the plant having the lowest number of stems per plant. The percentage of marketable tubers increases with the decrease in the size of the seed piece and with the increase in the number of sets cut from one tuber, according to the investigations of Aicher (1) and Welch (14). Aicher (2) has shown that the percentage of marketable potatoes was less from whole seed tubers than from quartered tubers of the same size, and that 3-ounce tubers yielded more than 8-ounce tubers, all cut the same way. There is a progressively lower percentage of marketable tubers as the number of stems per hill increases.

EXPERIMENTAL DATA

There is a general feeling among potato growers in the South that northern-grown seed potatoes germinate slower than do southern or home-grown seed, that northern tubers produce a more sturdy and vigorous plant than do the native tubers, and that there is a tendency for northern seed to produce fewer shoots and consequently a larger percentage of marketable potatoes of higher quality than home-grown seed. This experiment was planned to answer some of the questions which have been raised relative to the physiological behavior of regional strains of potatoes when used for seed.

All tubers planted in this test were of the Early Ohio variety. The first trial was conducted at the University of Illinois. It in-

cluded three regional strains, *viz.*, those obtained from the Minnesota Branch Experiment Station at Crookston, which have been designated as "northern;" those from the Illinois Agricultural Experiment Station, at Urbana, which have been designated as "south-central;" and those obtained from a farm in Madison County, Illinois, which have been designated as "southern." Both the south-central and southern seed had been grown in their respective regions but 1 season and had come from the North the previous year, although the exact location of their source is not known. A similar test was made at the University of Wisconsin. This trial included four regional strains, *viz.*, one from Oconto County, Wisconsin, known as "northern;" another from Winnebago County, Illinois, designated as "north-central;" one from the Illinois Agricultural Experiment Station at Urbana, known as "south-central;" and a lot from Madison County, Illinois, designated as "southern." All except the northern strain were 1 year removed from the North, having been grown in their respective regions but 1 season. The exact source of their origin is not known. In both trials the plants were grown in the greenhouse, the period of growth for the first trial being 34 days and for the second 76 days.

The method of cutting the potatoes differed slightly in the two trials. In the first test, tubers were cut horizontally into four pieces of equal size, while in the second, they were cut into two pieces, a stem-end and a seed-end set. Likewise, for the longitudinal cuttings, the first trial consisted of four equal parts and the second of two. In both trials, whole tubers and small irregular sets of approximately two eyes were also used. These small sets were secured by cutting oblique sections from the tuber, beginning at the stem end. The seed-end pieces contained more than two eyes. In choosing tubers for this experiment, only those of similar size and shape were taken.

All plantings were made under uniform conditions. The soils used were dark rich loams. The moisture of the soils and the temperature of the rooms were maintained at optimum conditions for growth. Before planting, a record was made of the number of eyes per tuber for the different regional strains, as shown in Table 1. At the end of the respective growth periods data were obtained on the number of shoots per hill (Table 2), the height and diameter of shoots (Table 3), the time of emergence of the shoots (Table 4), and on the branching habit of the plants (Table 5).

DISCUSSION

The data obtained indicate that there is a gradual increase in the number of eyes per tuber as the region of production extends south-

TABLE 1.—*The effect of source of seed potatoes on the number of eyes per tuber, University of Illinois plant physiology greenhouse.*

Source of seed	Average number of eyes
Northern	15.2
South-central	16.2
Southern	17.7
All sources	16.4

TABLE 2.—*The influence of source of seed potatoes and method of cutting on the average number of stalks per hill.**

Method of cutting	Trial	Source of seed tubers				
		Average of all sources†	Northern	North-central	South-central	Southern
Average	Both	4.61	2.20	—	5.73	5.89
	1st	4.18	2.06	—	4.79	5.70
	2nd	5.03	2.34	3.42	6.67	6.08
Whole	Both	6.73	2.67	—	8.17	9.34
	1st	6.56	2.67	—	7.00	10.00
	2nd	6.89	2.67	3.67	9.33	8.67
Horizontal, two and four pieces‡	Both	4.42	2.00		6.21	5.04
	1st	4.17	2.00	—	5.75	4.75
	2nd	4.67	2.00	3.33	6.67	5.33
Longitudinal, two and four pieces‡	Both	4.11	2.21	—	5.00	5.13
	1st	3.33	1.75	—	4.00	4.25
	2nd	4.89	2.67	3.67	6.00	6.00
Two eyes per piece§	Both	3.17	1.90	—	3.54	4.07
	1st	2.67	1.80	—	2.40	3.80
	2nd	3.67	2.00	3.00	4.67	4.33

*First trial was conducted at the University of Illinois; the second trial at the University of Wisconsin.

†Results of north-central seed are not averaged in total, since only one trial was made.

‡Tubers were cut into four pieces first trial and two pieces second trial.

§The seed-end piece contained more than two eyes.

ward (Table 1). This increase averaged 2.5 eyes per tuber with seed from northwestern Minnesota compared to seed grown in southwestern Illinois, a distance of more than 600 miles. It is doubtful if this difference can in any way explain the variation in the number of stems obtained from these regional strains. Not all of the eyes grow when whole tubers are planted, while more than one stalk may come from a single bud of a seed piece. These facts alone offset any significance that may be attached to the greatest number of eyes being associated with the strain of more numerous stalks.

Source of seed potatoes has a significant influence upon the number of stalks arising from one seed piece, and these in turn upon the per-

TABLE 3.—*The influence of source of seed tubers and method of cutting on the height and diameter of potato plants.**

Method of cutting	Trial†	Source of seed and growth factor in cm									
		Average‡		Northern		North-central		South-central		Southern	
		Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter
Average	Both	36.24	0.94	34.27	1.19	—	—	37.49	0.83	36.95	0.79
	1st	31.65	0.94	25.45	1.18	—	—	35.19	0.88	34.31	0.75
	2nd	40.82	0.94	43.08	1.20	32.67	0.92	39.79	0.78	39.58	0.82
Whole	Both	39.43	1.01	40.40	1.34	—	—	40.60	0.84	37.29	0.84
	1st	30.19	1.04	19.46	1.27	—	—	34.70	0.95	36.40	0.90
	2nd	48.67	0.97	61.33	1.40	34.83	1.18	46.50	0.73	37.17	0.78
Horizontal, two and four pieces§	Both	36.81	0.92	39.14	1.16	—	—	36.15	0.79	35.15	0.81
	1st	32.17	0.83	27.94	1.07	—	—	34.29	0.71	34.29	0.71
	2nd	41.44	1.01	50.33	1.27	20.00	0.65	38.00	0.87	36.00	0.90
Longitudinal, two and four pieces§	Both	31.67	0.89	29.61	1.14	—	—	35.21	0.82	30.18	0.70
	1st	34.72	0.87	32.39	1.15	—	—	38.74	0.79	33.02	0.67
	2nd	28.61	0.90	26.83	1.12	34.00	1.07	31.67	0.85	27.33	0.73
Two eyes per piece‖	Both	37.04	0.92	27.92	1.12	—	—	38.01	0.85	45.18	0.79
	1st	29.52	1.00	22.00	1.21	—	—	33.02	1.05	33.53	0.73
	2nd	44.55	0.84	33.83	1.02	41.83	0.77	43.00	0.65	56.83	0.85

*First trial was conducted at the University of Illinois; the second at the University of Wisconsin.

†First trial was planted April 10 in University of Illinois greenhouse and data taken May 14, growth period 34 days. Second trial was planted April 4 in University of Wisconsin greenhouse, data taken June 19, growth period 76 days.

‡Results of North-central seed are not averaged in total since only one trial was made.

§Tubers cut into four pieces first trial and two pieces second trial.

‖The seed-end piece contained more than two eyes.

TABLE 4.—*The influence of source of seed potatoes and method of cutting on the number of days required to emerge.**

Method of cutting	Trial	Source of seed tubers				
		Average of all sources†	Northern	North-central	South-central	Southern
Average.. ..	Both	15.18	18.33	—	13.67	13.05
	1st	13.66	16.98	—	12.42	11.58
	2nd	16.67	20.67	16.59	14.92	14.42
Whole	Both	16.73	22.34	—	14.00	13.84
	1st	15.11	20.00	—	12.67	12.67
	2nd	18.33	24.67	16.67	15.33	15.00
Horizontal, two and four pieces‡.	Both	14.78	17.04	—	13.25	14.04
	1st	13.67	15.75	—	12.50	12.75
	2nd	15.89	18.33	18.33	14.00	15.33
Longitudinal, two and four pieces‡.	Both	14.80	17.88	—	12.59	13.92
	1st	12.92	14.75	—	11.50	12.50
	2nd	16.67	21.00	14.67	13.67	15.33
Two eyes per piece§.........	Both	15.03	18.04	—	14.84	12.20
	1st	14.27	17.40	—	13.00	12.40
	2nd	15.78	18.67	16.67	16.67	12.00

*First trial was conducted at the University of Illinois; the second trial at the University of Wisconsin.

†Results of north-central seed are not averaged in total since only one trial was made.

‡Tubers cut into four pieces first trial and two pieces second trial.

§The seed-end piece contained more than two eyes.

TABLE 5.—*The effect of source of seed potatoes and method of cutting on the average number of branches per plant, Madison, Wisconsin.*

Method of cutting	Source of seed				
	All sources	Northern	North-central	South-central	Southern
Average of all methods.	1.17	2.50	1.42	0.42	0.33
Whole...............	3.25	4.33	5.67	1.67	1.33
Horizontal into two pieces............	0.75	3.00	0.00	0.00	0.00
Longitudinal into two pieces....	0.58	2.33	0.00	0.00	0.00
Two eyes to the piece*..	0.08	0.33	0.00	0.00	0.00

*The seed-end piece contained more than two eyes.

centage of marketable tubers. Northern seed sent up less than half the number of stems produced by southern seed (Table 2). It is interesting to note that there is a gradual increase in the number of stalks per seed piece as the source of seed potatoes goes from north to south.

There is less difference between the two northern strains or the two southern strains than there is between the northern group and the southern group. For example, the average number of stems for the northern strain was 2.20 per seed piece, while for the north-central strain it was 3.42 stems per seed piece, a difference of 1.22 stems. The south-central strain averaged 5.73 stems per seed piece and the southern strain 5.89 stems per seed piece, or a difference of 0.16 stem, while the difference between the northern strains as a group and the southern strains was 3.00 stalks per seed piece. The

FIG. 1.—Regional strains of the same variety of potatoes (Early Ohio) exhibited marked differences in growth even where the seed pieces were cut uniform in size and number of eyes.

The tubers were cut with two eyes to a piece except the seed-end sets. The pictures represent plants grown from seed pieces second from the stem-end. The northern strain produced the most desirable plants from the point of view of number of stems per hill and size of plants. It averaged 1.8 stems per hill, the south-central 2.4, and the southern 3.8. Height of shoots varied as follows: Northern, 22.00 cm, south-central 33.02 cm, and southern 33.53 cm. Stems of the northern strain averaged 1.21 cm in diameter, south-central 1.05 cm, and southern 0.73 cm. Plants of the northern strain usually emerged several days later than the southern strain. (Tables 2, 3, and 4.) Planted April 10, in Plant Physiology greenhouse, Urbana, Illinois; photographed May 14.

south-central seed acted very much like southern-grown potatoes. In fact, the average number of shoots per seed piece for the south-central seed was greater in the second trial than that for the southern. It seems that after a certain degree of degeneration is reached, further deterioration in potatoes caused by their being grown farther south is relatively slight. In going from central Illinois to northern Illinois, a distance of 150 miles, the number of stems produced per seed piece was reduced nearly one-half. From these data it seems that northern

Illinois grown seed potatoes would be much more desirable than central Illinois grown seed. The marked difference in the response of tubers grown in these two regions is significant. Northern Illinois may be termed the doubtful region, while central Illinois is a poor area for potato seed production. Based upon the number of stalks desired per hill and the influence of the region upon this characteristic, a fairly definite line could be drawn separating the region of good seed production from that of poor seed production.

FIG. 2.—Regional strains of the same variety of potatoes (Early Ohio) when cut uniform in size and shape showed marked differences in size and number of stems per plant.

The pictures represent plants grown from similar seed pieces obtained by cutting tubers into quarters longitudinally. The northern strain produced only a few (1.75) well proportioned stems per hill, whereas the south-central and southern produced 4.00 and 4.25 stems per hill, respectively. Stems of plants grown from northern seed were strong enough to stand erect. They averaged 32.39 cm. high and 1.15 cm in diameter, the south-central averaged 38.74 cm high and 0.79 cm in diameter, while the plants grown from southern seed averaged 33.02 cm high and 0.67 cm in diameter. The southern strains began growth several days earlier than the northern strain. (Tables 2, 3, and 4.) Planted April 10, in Plant Physiology greenhouse, Urbana, Illinois; photographed, May 14.

The northern-grown strain of potatoes from Minnesota was produced nearly 200 miles north of the Wisconsin strain, but both had about the same number of stalks per set. A comparison in this respect is not very reliable because the data on the two strains was not obtained the same year. The results at least indicate that after a certain point is reached little improvement occurs in seed potatoes grown still farther north.

The method of cutting the tubers has influenced the number of shoots markedly. The whole sets on the average produced more than twice the number of stalks as the two-eye sets. Reducing the

size of the seed piece has greater effect on the southern than on the northern grown seed in lowering the number of stems per set.

In view of the fact that northern strains of potatoes required a longer period to emerge from the soil, they were not as tall as the southern strains during the early period of growth. Later in the season the northern strains surpassed the southern plants in height (Table 3). The stems of northern strains continued to be much thicker than the southern throughout the period of growth. The stalks

FIG. 3.—Variation in type and general vigor of potato plants grown from different regional strains of the same variety.

The tubers were cut transversely into quarters. Picture represents plants grown from seed-end pieces. The northern strain produced the most desirable plants from point of view of number of stems per hill and vigor of plants. It averaged 2.00 stems per hill, the south-central 5.75, and the southern 4.75. The spindling nature of the southern strains is noted in the disproportionate size of the haulms. Stems of the northern strain averaged 27.94 cm high and 1.07 cm in diameter; the south-central, 34.29 cm high and 0.71 cm in diameter; and the southern strain 34.29 cm high and 0.71 cm in diameter. Shoots from the northern strain emerged several days later than from the southern strain. (Tables 2, 3, and 4.) Planted April 10, in Plant Physiology greenhouse, Urbana, Illinois; photographed May 14.

of the southern strains appeared weak and spindling compared to the stalks of northern strains. The sturdiness of plants resulting from the use of northern seed is in striking contrast to plants from southern seed (Figs. 1 to 4).

On the average, whole tubers gave the largest plants, while longitudinal cuttings gave the smallest plants. Two-eyed sets gave plants which compared favorably with those from whole sets.

From the data recorded in Table 4, it will be noted that northern-grown potatoes required a longer period to emerge from the soil than southern seed. This tendency has been consistent throughout the experiments. While whole tubers required the most time for emer-

gence, yet the variation for the different methods of cutting was not great.

The branching habit of the potato stem seems to be correlated with strong, vigorous plants. Northern plants branched for all methods of cutting, although this was not true for the other regional strains. To be sure, whole tubers gave the most branches, while two-eyed sets yielded the least (Table 5). The branching of the potato plant appears to accompany a tuber with an abundant food supply

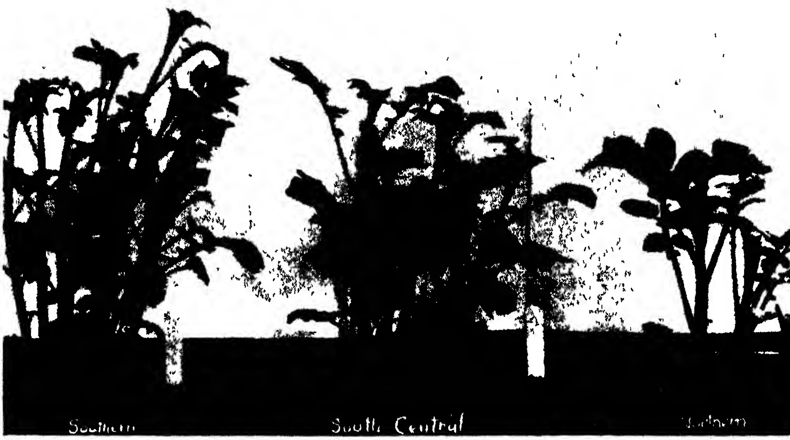

FIG. 4.—The marked difference in the number of stems produced by whole tubers of uniform size and shape from different regional strains of Early Ohio potatoes.

The pictures represent plants grown from whole tubers The tendency of the northern strain to produce a few stems per hill is very evident. The average number of stalks per hill is as follows: Northern 2.67, south-central 7.00, and southern 10.00. Vigor of growth is revealed in the size of the stems. The northern strain averaged 19.46 cm high and 1.27 cm in diameter; the south-central, 34.70 cm high and 0.95 cm in diameter; and the southern, 36.40 cm high and 0.90 cm in diameter. Shoots of the southern strain appeared above ground 1 week earlier than the shoots of the northern strain. This fact must be considered in noting size of plants. (Tables 2, 3, and 4.) Planted April 10, in Plant Physiology greenhouse, Urbana, Illinois; photographed May 14.

and with a small number of stems. The significance of the branching plant is only conjecture, since none was grown to maturity so that yields could be measured. It is the opinion of the author, however, that the branched plant as encountered in these experiments would yield higher than non-branched plants. The former are to be found only in hills of few stems. The number of tubers produced per hill would be small, while the photosynthetic area of the plant would be large. Again, branching was associated only with strong vigorous plants. These facts lead one to infer that the branched plant is to be preferred.

CONCLUSIONS

The results of this experiment indicate that the number of eyes per tuber is greatest for southern strains, but probably has no significance relative to yields when whole tubers are planted.

Northern strains of potatoes produce fewer stalks per seed piece than other strains. The area for seed potato production may be determined roughly by planting the tubers from various regions and noting the number of stalks per hill. Small seed pieces produce fewer stalks than whole tubers when planted.

Plants resulting from the use of northern seed are more vigorous than those from southern seed. Whole tubers give the largest plants and transverse sections the smallest.

The time required for shoots to emerge from the soil is greatest for northern strains and whole tubers and shortest for southern strains and sections of a tuber.

Since only strong, vigorous stems produce branches, the branching habit may be associated with high yield.

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A TEST FOR REPLACEABLE AND WATER-SOLUBLE POTASSIUM IN SOILS[1]

R. H. BRAY[2]

The amount of replaceable potassium present in soils has received much study during recent years. It is generally considered to be a source of potassium for the soil solution, and therefore, to be more or less available for plant growth. Some of the factors which may affect the amount of potassium given up to the soil solution by the replaceable form and, therefore, its availability, are the amount of potassium present in the replaceable form, the magnitude of the base exchange capacity, the degree of saturation with bases other than potassium, and the amounts of water-soluble salts or acids present. Of these factors, the amount of replaceable potassium present is probably the most important.

The following test was worked out in this laboratory as a rapid means of determining the approximate amounts of replaceable and, incidentally, water-soluble potassium present in soils, with the hope that it would be of use in soil fertility studies.

THE TEST

The test is made by extracting the soil with a sodium acetate-nitric acid solution, precipitating the potassium in an aliquot of the filtrate as the cobaltinitrite, and reading the amount of precipitate by means of the turbidity of the solution when it is first formed. A standardized turbidity chart is used for the reading. The solutions necessary for making the test are as follows:

Reagent A.—One thousand grams of C. P. sodium acetate are dissolved in 1,600 cc of water. Seven parts of this solution are mixed with 3 parts of 1:1 nitric acid to make reagent A.

Reagent B.—A cobaltinitrite solution is made according to Bennett,[3] in which 50 grams of $Co(NO_3)_2$ and 300 grams of $NaNO_2$ are dissolved in water acidified with 25 cc of acetic acid, and made up to a liter with water. The solution is allowed to stand for 24 hours and then filtered.[4]

Reagent C.—95 per cent ethyl alcohol.[5]

[1]Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Received for publication August 18, 1931.

[2]Associate in Soil Survey Analysis.

[3]BENNETT, ALEX H. The estimation of potassium in presence of other substances. Analyst, 41: 165–168. 1916

[4]Tests indicate that the solution is not quite as sensitive when first made up as after standing 2 or 3 days. This solution has been found to be good up to 7 months, giving only slightly less turbidity at the end of that period.

[5]LUTZ, O. Sensitivity and applicability of qualitative reactions. I. Potassium ion. Zeit. anal. Chem., 59: 145–65. 1920.

PROCEDURE

Two and one-half grams of air-dried soil are placed in a small beaker with a measured amount of reagent A. The mixture is stirred for ½ minute and filtered through a dry 7-cm quantitative filter paper. One cc of the filtrate is measured into a small flat-bottomed vial of the same size as used in standardizing the turbidity chart. Four drops of reagent B (20 drops = 1 cc) are added, mixed, and then 1 cc of reagent C is slowly added down the side of the inclined vial so that very little mixing takes place. The vial is then gently shaken, thus slowly mixing the two solutions. When thoroughly mixed, the solution is allowed to stand for 1 minute before reading the precipitate on the turbidity chart. The directions for adding and mixing the reagents should be closely followed.

STANDARDIZATION AND USE OF THE TURBIDITY CHART

The test, when developed according to the above directions, results in a turbid solution if sufficient potassium is present. Advantage is taken of the degree of turbidity to estimate the amount of the potassium cobaltinitrite present by the clearness with which one can see, through a definite depth of the solution, different sets of lines drawn on a white cardboard with a ruling pen Each set consists of five lines of the same breadth and color, the lines being 0.3 cm apart and at least 4 cm long. Two colors are used, a light green and black, and in the different sets the thickness of the lines varies from as thin as it is practical to make them to approximately 0.1 cm thick. Sanford's green ink No. 260, diluted with 1 part of distilled water, and Higgins' India ink diluted with 4 parts of distilled water, were found satisfactory in making the lines.

Readings can be made only within a range of a few parts per million of potassium, since too low a concentration produces little or no turbidity and one too high obscures the heaviest black lines. The range is covered by the standard potassium solutions given below which can be used for selecting the four appropriate sets of lines. Since the No. 2 solution gives an amount of precipitate easiest to read, it has been chosen as an "end point," as explained below.

A stock solution of potassium is made containing 0.3485 gram of potassium acid phosphate in a liter of reagent A. This is equivalent to 0.1 gram of potassium per liter. From this the following three solutions are made:

No. 1 = 6 cc stock potassium solution + 20 cc reagent A
No. 2 = 7 cc stock potassium solution + 20 cc reagent A
No. 3 = 8 cc stock potassium solution + 20 cc reagent A

One cc of solution No. 2 is developed according to the above directions. It is held about ½ inch above the cardboard, looking directly through the solution from the top of the vial, and is moved over the sets of lines until a point is found where one set of lines is obscured while the next heavier set is visible. The vials used by the writer gave a depth of solution of 1.5 cm for the 2.20 cc volume. The light from a north window on a clear day was always used. With this special strength of solution (No. 2) this point will be found to be between a set of medium thin light green lines and thin black lines. The point for the No. 1 solution is between the same medium thin light green lines and a set of very thin light green lines, while the point for the No. 3 solution is between the thin black lines and a set of rather thick black lines.

The four sets of lines chosen by use of the standard potassium solutions can later be used only with the same sized vials as used originally in choosing them. Reagent B should be checked occasionally with the standard potassium solution once the sets of lines have been established. Different individuals will probably find it desirable to standardize their own sets of lines because of differences in vision.

Roughly quantitative results on soils are secured by extracting a series of 2.5-gram samples with, for example, 5, 7, and 9 cc, respectively, of reagent A. Readings are made on the 1-cc aliquots and a test corresponding to the test secured with the No. 2 standard potassium solution is taken as an end point. If a No. 2 reading is not obtained, tests at other dilutions must be made. Four cc is the smallest amount of reagent A which can be used for extracting most soil samples and 44 cc is the largest amount which has been tried.

Since the No. 2 precipitate is produced by a definite amount of potassium in the No. 2 standard solution, a factor can be calculated which, when multiplied by the number of cc of reagent A used for the extraction, will give the amount of potassium extracted from the soil in terms of milligram equivalents per 100 grams of soil. This factor is 0.026.

RESULTS WITH SOILS OF KNOWN REPLACEABLE POTASSIUM CONTENT

Table 1 gives some results secured with the test compared with the quantitative results obtained by extracting with ammonium acetate and determining potassium in the extract as the perchlorate. All test values were found by using 1-cc increments of reagent A and taking the No. 2 reading as an end point. Results were reproduceable

to within 0.5 to 1 cc in the 4 to 10 cc dilution range and at greater dilutions the reproduceability was proportional.

TABLE 1.—*Comparison of test with quantitative method for potassium in soils of known replaceable potassium content.*

Laboratory No.	Milligram equivalents of replaceable potassium in 100 grams of soil	
	Cc dilution to obtain the No. 2 reading x 0.026	Quantitative value
S6755	—*	0.05
S6763	—*	0.05
S6762	0.10	0.12
S6766	0.18	0.12
S6754	0.16	0.16
S6760	0.18	0.16
S6768	0.26	0.16
S6761	0.16	0.17
S6765	0.16	0.17
S6767	0.16	0.20
S6757	0.21	0.23
S6758	0.26	0.26
S6756	0.34	0.30
S6764	0.29	0.32
S6759	0.36	0.36
13051	0.94	0.97
13054	1.09	1.06

*Precipitate too light to read at 4 cc dilution.

The test was designed as a rapid approximate method and a minimum of equipment was used. For the values in Table 1, the soils were measured in a 2.5 cc brass cup, while reagents A, B, and C and the aliquots to be tested were measured with pipettes and calibrated medicine droppers. The dilution of the filtrate, where a heavy precipitate is obtained, instead of repeated extractions at greater dilutions of the reagent, may be possible, but was not fully investigated. In general, the measuring of the samples instead of weighing them will involve an error no greater than 0.1 gram for most silt loams, although sample S6768 consistently measured more nearly 3 grams than 2.5 grams.

Fifty samples on which quantitative values had already been secured were run with this test. These samples varied in potassium extracted from 0.05 milligram equivalent to approximately 1 milligram equivalent per 100 grams of soil. They represented soils from some of the experiment fields located in different parts of Illinois, and also various samples analyzed during a soil type profile study. Since both groups of soils gave results in equally good agreement with those obtained by the standard quantitative method, only data from the experiment fields are given here with the exception of Nos. 13051 and

13054 from the A and B horizons, respectively, of Type 14A, which were included because of their high values.

None of the ions in the amounts commonly extracted from soils by a salt solution appear to influence the test. The ammonium ion, which may be present in small amounts or, under special conditions, in larger amounts, gives a test only in concentrations a great deal higher than would be extracted from the ordinary soil. The test itself is also approximately four times as sensitive to the potassium ion as it is to the ammonium ion.

NITROGENOUS FERTILIZERS ON SMALL GRAINS FOLLOWING SORGHUMS[1]

JOHN P. CONRAD[2]

The results of two years' work with the fertilization of small grains following sorghums have already been published (2, 3)[3]. The hypothesis (1) that the injury of sorghums to succeeding crops is due to the presence of toxins in the soil resulting from the decomposition of the sorghum residues seems to us inadequate for the conditions of our experiments, at least, in view of the data already published.

Since the appearance of the data referred to above, Hughes and Henson in their textbook (4, p. 151) cite work which implies that sorghum injury is due to toxic decomposition products in the soil. This reflects the point of view of a part of the other investigators with whom the writer has had a chance to discuss this problem.

Two additional years of work have now been completed. The data secured from them give further strength to those already published. The results of these fertilizer trials may also be of some interest aside from their connection with the sorghum injury.

These experiments were conducted at the University Farm, Davis, in the Sacramento Valley, and at the Imperial Valley Experiment Station[4] near El Centro.

EXPERIMENTS AT DAVIS

Fargo milo was planted on an area of 1/5 acre in the spring of 1928. After maturity the stalks were removed, and skips and morn-

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication August 22, 1931.

[2]Associate Agronomist.

[3]Reference by number is to "Literature Cited," p. 321.

[4]The writer is indebted to L. G. Goar and J. B. Goar, Foremen, Imperial Valley Experiment Station, for carrying out the experiments there.

ing-glory spots avoided in planning the location of sub-plats. Each sub-plat was 6 feet by 20 feet. Atlas barley was planted Nov. 24, 1928, and sulfate of ammonia was dissolved in water and applied with a sprinkling can on February 20, 1929. The plats were irrigated April 3 as the spring was a dry one. The data secured are summarized in Table 1.

TABLE 1.—*Effect of applications of sulfate of ammonia on the yield of barley following Fargo milo at Davis, 1929.*

Fertilizer per acre, lbs.	Number of sub-plats	Average yield threshed barley per acre, lbs.
Unfertilized checks	12	1,755
100	5	1,900
200	5	2,650
400	5	3,450

A more accurate way of evaluating the increases due to the fertilizer would be to compute from the yield of the check sub-plats the yield by interpolation of the sub-plat if it were not fertilized and then to compute the increase. Using this method, the following results were secured for the 1929 season:

Sulfate of ammonia, lbs.	Increased yield, pounds per acre	Significance, Student's odds
100	315	26.5
200	900	5,000
400	1,610	900

On November 9, 1929, a plat which had been in a uniform stand of Fargo milo was planted to 10 6-foot drill widths of Atlas barley each 120 feet long. Each strip was divided into sub-plats 6 feet by 20 feet with alleys in between. Strips 1, 4, 7, and 10 were used for check plats exclusively. Differential fertilizer treatments were placed in the other six strips. Both nitrate of soda, containing 16.37% nitrogen, and sulfate of ammonia, containing 21.03% nitrogen, were used and comparisons of approximately equal amounts of nitrogen applied in the two forms were made in adjoining sub-plats. The replications were systematically distributed through the strips. The fertilizer, dissolved in water as before, was applied February 15, 1930, when the plants were about 4 inches high. At harvest time border rows were discarded, and yields computed on the basis of yields of areas each 4 feet by 20 feet. Table 2 gives the yield data and the significance of the increases computed by Student's method (5). As the two sub-plats receiving approximately the same amount of nitrogen,

TABLE 2.—*Increases in the yield of barley following Fargo milo due to nitrogen fertilizers applied at Davis 1930.*

No. of Repli-cations	Fertilizer applied	Amounts applied per acre, lbs.		Increase in threshed grain, lbs. per acre	Significance, Student's odds	
		Ferti-lizer	Ni-tro-gen		Ferti-lized better than unfer-tilized	$NaNO_3$ better than $(NH_4)_2SO_4$
4	Nitrate of soda..	100.0	16.37	740	10,000	
4	Sulfate of ammonia	77.8	16.36	375	98	
	Difference ..			365		31.7
4	Nitrate of soda	200.0	32.74	925	400	
4	Sulfate of ammonia	155.6	32.72	730	40.7	
	Difference			195		6.7
4	Nitrate of soda	400.0	65.48	1,964	2,500	
4	Sulfate of ammonia	311.2	65.44	1,314	832	
	Difference .			650		49.5
3	Nitrate of soda	600.0	98.22	2,515	4,000	
3	Sulfate of ammonia	466.8	98.16	2,015	400	
	Difference			500		17.3

one as nitrate of soda and the other as sulfate of ammonia, were adjacent to each other, comparisons of the relative increases are entirely justified by the use of Student's method and are here included. In the table under "replications" are given the number of plats in each treatment.

EXPERIMENTS AT EL CENTRO

In 1929, fertilizer tests were conducted with ammonium sulfate, both following Double Dwarf milo and following Heileman milo, a selected strain of Dwarf Yellow milo. Small grains planted December 18, 1928, following Double Dwarf milo were fertilized on January 25, 1929, with ammonium sulfate dissolved in water as a top dressing. The plats were then irrigated. The results are given in Table 3.

TABLE 3.—*The increases in yield of small grains following double dwarf milo at El Centro, 1929.**

Crop	Ammonium sulfate, lbs. per acre	Increase in threshed grain, lbs.	Student's odds
Wheat	200	472	120
Oats	200	364	41.3
Barley	200	687	1,250
Barley	400	1,290	345
Barley	600	2,020	2,200

*Each increase number is the average of 4 separate increases.

TABLE 4.—*Increases in yield in pounds per acre of threshed barley and wheat resulting from applications of sulfate of ammonia to these crops following Heileman milo at El Centro, 1929.*

Time of application	Sulfate of ammonia applied, lbs. per acre							
	200	Odds	400	Odds	600	Odds	900	Odds
				Barley				
Dec. 18, 1928	262	13	1,308	90	—	—	—	—
Jan. 25, 1929	625	44.5	1,435	280	1,910	272	2,520	367
Feb. 28, 1929	718	152	1,540	328	1,623	356	—	—
Mar. 21, 1929	577	86	954	64	—	—	—	—
				Wheat				
Dec. 18, 1928	188	32	829	1,150	—	—	—	—
Jan. 25, 1929	675	860	1,025	610	1,385	3,300	1,593	1,700
Feb. 28, 1929	486	27.7	1,143	1,800	1,255	350	—	—
Mar. 21, 1929	440	44.5	610	624	—	—	—	—

TABLE 5.—*Increases in the yield of barley following Heileman milo at El Centro due to nitrogenous fertilizers applied, 1930.*

Fertilizer applied			Increases threshed grain, lbs. per acre	Significance, Student's odds in relation to 1
Kind	Date	Pounds per acre		
		1929		
$NaNO_3$	Dec. 23*	255	1,257	800
$(NH_4)_2SO_4$	Dec. 23	200	855	43
		1930		
$NaNO_3$	Jan. 26	255	1,253	67
$(NH_4)_2SO_4$	Jan. 26	200	653	9.7
$NaNO_3$	Jan. 26	511	2,466	400
$(NH_4)_2SO_4$	Jan. 26	400	2,043	81
$NaNO_3$	Jan. 26	766	1,837	6.5
$(NH_4)_2SO_4$	Jan. 26	600	2,223	217
$NaNO_3$	Feb. 26	255	1,445	72
$(NH_4)_2SO_4$	Feb. 26	200	1,137	136
$NaNO_3$	Mar. 21	255	1,618	600
$(NH_4)_2SO_4$	Mar. 21	200	663	215

*All plantings made Dec. 23, 1929.

More extensive experiments were undertaken with both wheat and barley following the Heileman milo. The time of applying the fertilizer was also varied. Each time the fertilizer was dissolved in water and applied to the appropriate sub-plat with a sprinkling can. Table 4 gives for each different fertilizer treatment the average of the increases above the computed yield of the same sub-plats figured by interpolation from yields of adjoining unfertilized check sub-plats. Each treatment was represented by four different sub-plats distributed over the area in such a way as to minimize the effect of soil differences Under Student's odds are given the odds in relation to unity by Student's method (5).

In 1930, both nitrate of soda, containing 16.37% nitrogen, and sulfate of ammonia, containing 21.03% nitrogen, were used. The yields (Table 5) were somewhat more variable than the year before and for the same year at Davis, hence the differences in favor of nitrate of soda over sulfate of ammonia are not supported by as high odds. The increases due to fertilizers applied are in the main significant, however.

DISCUSSION

The experimental results given in this and in previous papers clearly show that for the conditions obtaining in these experiments, small grains following sorghums are benefited by applications of nitrogenous fertilizers.[5] The benefits as measured by increases in yield are roughly proportional to the amount of fertilizer applied. It would be most natural to suppose that the poor growth of the unfertilized small grains here was due to deficiency of nitrogen in available form. This is not the only interpretation possible as Schreiner and Reed (6) have secured decreased toxicity in solution culture by the addition of $NaNO_3$ or $CaCO_3$. In Skinner's (7) experiments vanillin depressed the yield of clover on the same soils that it depressed the yield of wheat. It would appear from his experiments that some soils exist upon which vanillin and other toxins are not injurious. In the field at Arlington Farm, vanillin also depressed the yield of cowpeas, string beans, and garden peas.

In the experiments at Davis, no reduction in yield of legumes following sorghums as compared with yield following fallow have been statistically demonstrated. In fact, in the experiments already

[5]In 1929, in a test not reported herein, no increase was secured from nitrogenous fertilizers on barley following milo. At no time during the growth was any injury apparent, i. e., yields of both unfertilized and fertilized plats were exceptionally good. Growers of sorghums on very fertile soil notice very little, if any, injury to succeeding crops of small grains.

published (3), the actual average yield of fenugreek after fallow was less than that following corn or sorghums, while the yield of barley after fallow was more than twice that following Honey sorghum. The work at El Centro had apparently shown some decreases with a few legumes after sorghums, while other legumes have not been decreased. This is to be made the subject of further study.

In Skinner's (7) experiments, vanillin, a toxin, decreased the yield of both legume and non-legume on soils where it decreased either, while the sorghums in our experiments at Davis have markedly decreased the following crops of non-legumes, while legumes in general have been decreased little, if any.

Even if any weight is given to the possibility that the toxins have been destroyed proportionately to the rate of application of these two nitrogenous fertilizers (which by the way are quite different chemically except for their nitrogen content), still the good growth of legumes is difficult to explain by the toxin hypothesis.

Two other hypotheses have been advanced to explain this injury. One, that of temporary soil "exhaustion" due to the heavy sorghum crop; the other, that crop residues of sorghum contain a much higher percentage of sugars than other crops, and therefore by furnishing food for micro-organisms cause competition between them and the higher plants grown. Either hypothesis or a combination of both easily account for what is found in the field, at least as far as the conditions of our own experiments are concerned, but the toxin hypothesis leaves very much to be desired. If fertilizer trials on non-legumes and tests of legumes following sorghums are tried more generally over the regions where sorghums are grown, much additional evidence would be available as to the general applicability of these results.

Reference is made in an earlier publication (2) to the possibilities of soil-moisture deficiency being a cause of sorghum injury. No such possibility existed in these experiments as irrigation water is normally applied for all of the growth at El Centro, while at Davis it was supplied to supplement natural precipitation in time of drought.

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METHODS FOR PREPARING A SEEDBED FOR WINTER WHEAT[1]

HORACE J. HARPER[2]

A review of the literature on the subject of seedbed preparation for winter wheat (1, 2, 3, 4, 5, 6)[3] indicates quite definitely that early plowing about 7 inches deep is a superior method when the average yields of wheat secured over a period of years are compared with results obtained from shallow plowing, listing, or discing the soil.

During the past few years two new tillage implements have been used in the preparation of the seedbed for winter wheat, *viz.*, the one-way disc and the Killefer chisel. (See Figs. 1 and 2.) The one-way disc is a very popular tool in the western part of the Great Plains region because large areas of land can be tilled in a short period of time and also the draft of the one-way disc is not excessive. A large part of the straw is left on the surface of the ground when either the one-way disc or Killefer chisel is used. This is an important factor in reducing wind erosion, particularly on the sandy soils where blowing is frequently a serious problem when the land is tilled with a mould board plow.

The Killefer chisel is a deep tillage implement and has been developed to loosen hard and compact subsoils without moving any of the subsurface soil to the top of the ground where it might have a bad effect on crop production and to provide conditions which are more favorable for root development.

EXPERIMENTAL

In the fall of 1927 an experiment was started at Stillwater, Okla., to compare the one-way disc with the Killefer chisel in order to determine which implement was the most desirable for use in the preparation of a seedbed for wheat. Six plats were selected for this study, each plat being 30 feet wide and 327 feet long. Each method

[1]Contribution from the Department of Agronomy, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Received for publication August 31, 1931.
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[3]Reference by number is to "Literature Cited," p. 328.

of seedbed preparation was repeated three times in order to reduce the possible error of soil variation. It was necessary to disc the land

FIG. 1.—Rear view of Killefer chisel manufactured by the Killefer Manufacturing Co., Los Angeles, Calif.

FIG. 2.—Rear view of one-way disc.

before the Killefer chisel would work efficiently because of the presence of pea vines and large weeds which would catch on the standards of the chisel and hold the soil so that frequent clogging occurred. Also a 10–20 tractor, which is a common source of power in the wheat area of the Great Plains region, could not pull this tool when all six of the chisels were attached. It was necessary to remove three of the standards before the power available could pull the Killefer efficiently.

The subsurface soil in this field is a compact clay, which is quite typical of many of the wheat soils in the Great Plains area. The Killefer was operated so that the chisels penetrated to a depth of 10 inches. Although the surface soil was dry, the subsurface soil was rather tough and was very difficult to stir. The surface soil was shattered between the chisels and was left in a porous condition. A mould board plow was used to turn the soil on the adjacent plats in the fall of 1927. The soil was turned about 4½ inches deep, which is similar to the depth which occurred when the one-way disc was used in the fall of 1928 and 1929. The power to operate the one-way disc, cutting a strip of land 8 feet wide and 4½ inches deep, was no greater than that required to pull the Killefer chisel set to run 10 inches deep and cultivating a strip only 2½ feet wide. Consequently, it is quite evident that the cost of preparing a seedbed with the one-way disc would be considerably less than with the Killefer chisel. The yields of wheat secured from this experiment are given in Table 1.

TABLE 1.—*Wheat yields produced on land prepared with a one-way disc and a Killefer chisel.*

Plat No.	Treatment	Yield of wheat per acre							
		1928		1929		1930		Average	
		Straw in lbs.	Grain in bu.	Straw in lbs.	Grain in bu.	Straw in lbs.	Grain in bu.	Straw in lbs.	Grain in bu.
1	One-way disc	1,438	17.3	1,520	16.7	1,660	8.2	1,539	14.0
2	Killefer chisel	1,523	14.1	1,190	14.5	1,080	4.8	1,264	11.1
3	One-way disc .	1,620	15.7	1,037	14.0	1,240	6.4	1,299	12.0
4	Killefer chisel	1,771	9.2	757	11.7	1,050	5.5	1,192	8.8
5	One-way disc .	1,936	16.4	880	14.1	1,470	7.9	1,428	12.8
6	Killefer chisel	1,683	13.4	1,130	14.4	910	4.9	1,241	10.9

Although the differences in yield between the different methods of seedbed preparation are not very great and the duration of the experiment rather brief, the Killefer chisel does not appear to be as good a tool as the one-way disc. Several other tests in which a Killefer chisel was used to stir the soil to a depth of 12 inches were conducted in Oklahoma during the season of 1927 and 1928, but no

appreciable difference in plant growth could be detected as compared with adjacent plats which were plowed 5 or 6 inches deep.

In another experiment which was located near Carrier, Okla., a study of different methods of handling straw following a combine harvester was made using a mould board plow, a lister, and a one-way disc as a means of preparing a seedbed for wheat. Both early and late seedbed preparations were studied, and with the exception of the last crop harvested, early seedbed preparation occurred each year about July 15 and late seedbed preparation about September 1. In the fall of 1930 all plats were tilled about September 1 and the yields secured in 1931 from plats previously prepared early and late are quite similar. Results secured during the last 4 years are given in Table 2.

TABLE 2. *A comparison of plowing, listing, and discing soil with a one-way disc as a means of preparing a seedbed for wheat.*

Plat No.	Treatment	Yield of wheat in bushels per acre				
		1928	1929	1930	1931	Average
1	Plowed early.	21 1	12 0	10.88†	26.16	17.53
2	Listed early.	16.0	8.6	9.66†	17.24	12.87
3	One-way disc early	15 3*	5.3	15.26	17 41	13.31
4	Plowed early	16.0	10.0	21 71	26.24	18.48
5	Listed early	13 7	7.8	18.62	15.83	13.98
6	One-way disc early.	16.7*	7 5	12.58	19.41	14.04
7	Plowed early.	17.6	13.0	23.85	27.91	20.59
8	Listed early	16.7	10.1	22.86	22.33	17.99
9	One-way disc early	17.5*	8.3	21.09	22.74	17.40
10	Plowed late	8 3	9 2	20.58	26.00	16.02
11	Listed late	7.0	7.6	12.17	15.58	10.58
12	One-way disc late.	6.9	6.2	10.01	13.74	9.21
13	Plowed late	7.3	9.4	17.15	25.41	14.81
14	Listed late	7.6	5.0	9.25	13.41	8.81
15	One-way disc late.	7.8	7.5	9.94	16.50	10.43
16	Plowed late	10.1	9.0	15.76	30.50	16.34
17	Listed late	8.2	7.0	10.88	14.58	10.19
18	One-way disc late.	8.1‡	7.0	11.82	18.08	11.25

*Disc plow used. †Badly winterkilled. ‡Estimated yield.

The average yields secured from the different methods of seedbed preparation are given in Table 3.

TABLE 3.—*Average yields secured from different methods of seedbed preparation.*

Treatment	Four-year average yield of triplicate plats in bushels per acre
Plowed early	18.86
Listed early	14.94
One-way disc early	14.91
Plowed late	15.72
Listed late	9.86
One-way disc late	10.29

The soil on which the above experiment was located is typical of a considerable area of the upland soils in the main wheat growing section of west-central Oklahoma. It is a friable brown sandy loam soil with a friable reddish brown sandy clay subsoil.

During the seasons of 1928, 1929, and 1930, the stubble on the area which was prepared late was disced thoroughly with a tandem disc at the time the early seedbed preparation area was treated. This treatment destroyed the grass and weeds and resulted in the conservation of considerable amounts of moisture. The early discing did not overcome the advantages secured from early plowing or listing. This is in accord with the results secured from previous experiments. In all cases plowing the soil has had an advantage over those plats which were listed. The difference in yield between the listed soil and those areas which were tilled with a one-way disc is not very great. Deep listing on this soil probably accounts for the reduced yield, especially in case of the late seedbed preparation study.

These data do not agree with results which have been secured at the Panhandle Agricultural Experiment Station at Goodwell, Okla., and at the Kansas Agricultural Experiment Station at Hays, which indicate that listing is just as good as, or even superior to, plowing from the standpoint of economical production. This is probably due to the lower amount of rainfall which occurs at these stations which does not pack the soil so much as the larger amount of rainfall which occurs farther east in this area.

It is quite evident from the data presented in Tables 2 and 3 that the continued use of the one-way disc is not so effective in producing conditions which are as favorable for the best growth of wheat as a mould board plow, especially on the heavier types of soil similar to that on which this experiment was located. Higher yields and a continuous wheat program mean a more rapid utilization of the plant food in the soil; consequently, the penalty for higher yields secured from plowing as compared with other methods of seedbed preparation may require a change in cropping system at an earlier date in order to maintain the nitrogen and organic matter content than on soils where poorer methods of seedbed preparation are used and the lower yields produced do not remove as much plant food from the soil.

DISCUSSION

Where the absorption of water might be a factor in crop production the Killefer chisel may have some advantages over the one-way disc. However, Chilcott and Cole (4) did not find that deep tillage had any appreciable influence on moisture conservation as

compared with ordinary soil treatment, and that deep tillage did not produce a profitable increase in yields of several different crops which were used in their experiments.

Deep tillage may be more useful on certain soils and in case of crops having a higher cash value per acre than wheat, such as potatoes and other truck crops. Also, the feeding power of the plant might be another factor to consider. However, root systems of plants can penetrate relatively compact soils when the soils are moist, and the chief effect of loosening most soils is probably due to the increased decomposition of organic matter and subsequent liberation of the minerals and nitrogen which they contain rather than any other influence which may occur.

The so-called "hard pan" in the Great Plains region is in most cases a soil containing a high percentage of clay which is plastic when wet, and even though it is broken apart by deep tillage it will run together again during the next rainy season. Deep tillage experiments at the Oklahoma Agricultural Experiment Station with kafir grown on a Kirkland loam soil which has a very compact B horizon have not produced any increase in yield over ordinary cultivation.

The one-way disc is well adapted to sandy soils which need protection from wind erosion. Also, most of the sandy soils in the wheat area of the Great Plains are not compact and are quite porous; consequently deep tillage under such conditions is not so important as in case of finer textured soils which pack easily under the influence of heavy rains or snow. It is also possible that the one-way disc would be more effective on the finer textured soils if the land was stirred deeper than is usually accomplished when this implement is used.

SUMMARY

Two experiments were conducted on methods of preparing a seedbed for wheat. In the first a one-way disc was compared with a Killefer chisel on a Kirkland loam soil near Stillwater, Okla. The second experiment was conducted near Carrier, Okla., on a soil which is typical of the best wheat land in the Great Plains region. A comparison was made using a mould board plow, a lister, and a one-way disc in the preparation of the seedbed. Tillage operations were made with each tool usually in July and September of each year.

The Killefer chisel required more power to operate than the one-way disc or mould board plow and did not in this experiment yield as much wheat as was secured where a one-way disc was used to prepare the seedbed. Where much vegetation occurred on the soil, the Killefer chisel was objectionable because it clogged easily due to

trash which collected on the standards supporting the chisels. The one-way disc operated satisfactorily even though large amounts of vegetation were growing on the soil.

Early plowing with a mould board plow produced much larger yields of wheat over a 4-year period than were secured when either a lister or a one-way disc was used in the preparation of the seedbed. In this experiment the use of the lister and a one-way disc produced about the same effect on the growth and yield of wheat.

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NOTES

MODIFICATIONS IN THE COLUMBIA DRILL FOR SEEDING OATS AND BARLEY

The Columbia drill is a widely used and efficient implement for seeding rod-row nursery material, especially wheat. However, none of the seed cylinders in the set regularly supplied are especially suitable for seeding oats and barley. As the drums are made of a very soft malleable cast iron it is relatively easy to convert some of the extra ones for use for special purposes. A key slot chisel (cape chisel), hammer, and visc are the only tools needed.

One of the cylinders having two alternate rows of round holes may be made to serve for seeding barley and oats if each pair of holes is united by cutting away the intervening metal. This leaves a number of diagonal oval cavities which handle the long grains of barley and oats very well. If a cylinder with a large number of cavities is used and the drive chain is adjusted so that the cylinder revolves at a low rate of speed, feeding from the hopper is quite positive and seeding is done evenly. The hopper brush may be adjusted to make the final regulation in the rate of seeding. Difficulty will be encountered in sowing barley that has not been threshed clean and oats that have large awns. Oats with a heavy test weight will pass through too rapidly.

Other cylinders may be prepared for planting small plats of corn that are to be spaced in the row rather than planted in hills. For this purpose a cylinder intended for planting very small seed may be used, as the small holes will not interfere. One cavity may be cut out and the space between drops determined while running at the proper

speed, after which enough more may be cut to drop kernels at the desired intervals.—N. E. JODON, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

A NEW FEATURE IN ROD-ROW THRESHERS

Many threshers for small quantities of grain have the fault of throwing out grain and chaff at the opening where the sheaves are fed into the machine. Not only does this fault of "spitting-back" make the feeding operation a disagreeable one, but a certain percentage of the grain is often lost and the scattering of kernels induces a possible mechanical mixture of varieties.

This note presents a new feature, a special device built into a small thresher which controls the air currents created by the rotating cylinder. The controlled air currents not only effect advantages in the feeding operations, but also increase the relative volume of air for cleaning the threshed material. Incidental to this particular feature, there is a device for recovering and cleaning the threshed material that requires only the air currents from the cylinder to fan the grain.

FIG. 1.—The Lind non-spitting rod-row thresher.

The nursery thresher[1] built and developed at this Station is a very simple one. The only moving part is the cylinder which threshes and fans the grain simultaneously. When in operation, the normal speed of the cylinder is about 1,300 R. P. M. The grain sheaves are inserted head first into the feeder hopper to thresh out all the heads, after which the straw is withdrawn and discarded. The grain is caught in a tray beneath the cylinder which is then pulled out part way to permit cleaning by the air draft created by the rotating

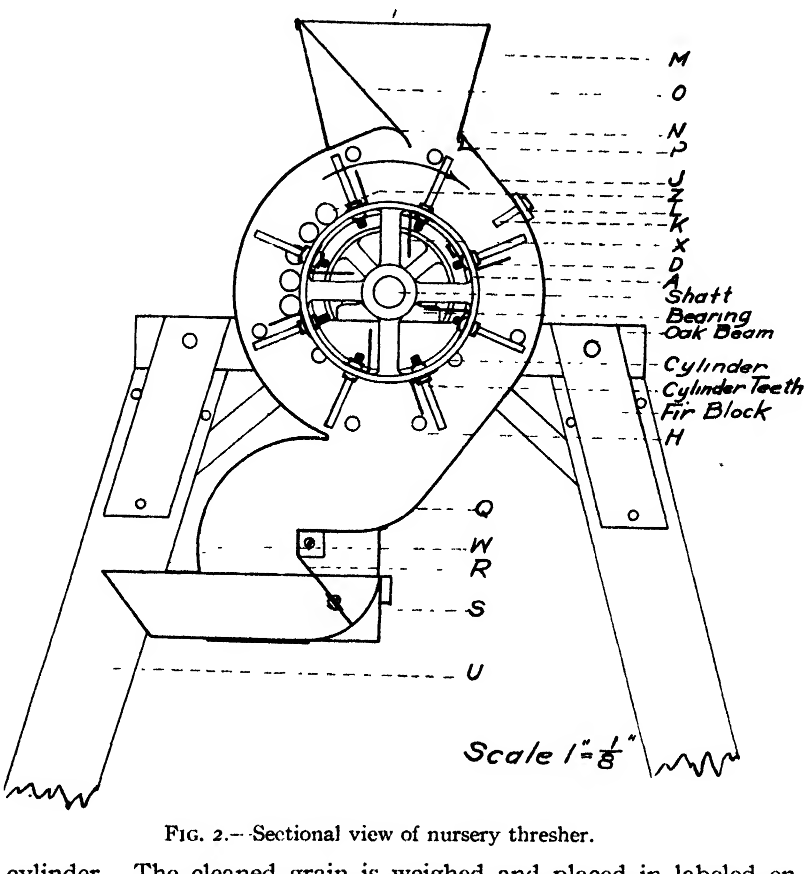

FIG. 2.—Sectional view of nursery thresher.

cylinder. The cleaned grain is weighed and placed in labeled envelopes. For the complete operation, less than a minute is required per sample and only two persons are needed for the operation.

As usual after the construction of the first machine, many faults were discovered. Before the machine could be used the feeder hopper had to be reduced in size at the base to remove feeding hazards. (See Figs. 1 and 2.)

[1]The application of the general principle in the utilization of the air forces developed by the rotating cylinder was characterized by Hoffman in Agr. Eng., 6:297–298. 1925.

The machine was remodeled when it proved unsatisfactory. To eliminate spitting, an especially designed sheet metal piece *N* (Fig. 4), called the wind director, was installed at the base of the hopper *M*. This piece was designed with reference to the nature of the peripheral air current created by the revolving cylinder. The peripheral

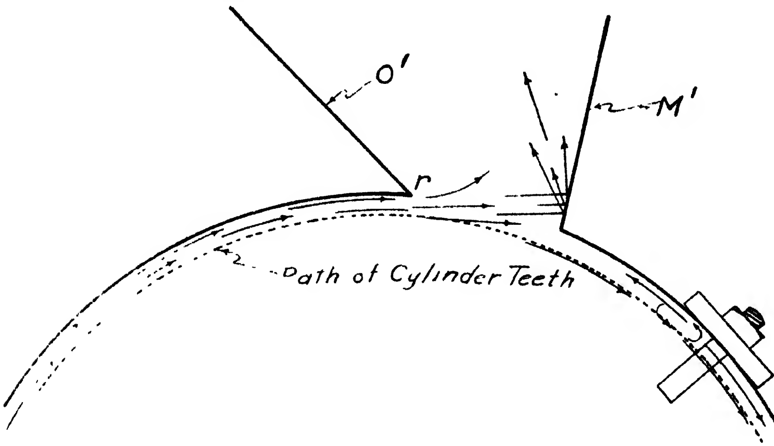

FIG. 3.—Sketch showing the natural air currents when not controlled.

velocity of the tooth point under normal operating conditions was 65 feet per second. At this speed sufficient air pressure was created between the teeth and the cylinder housing to accentuate the force of the air which passed beneath the hopper opening. If this air were not directed, it would pass off into space at a tangent with the curved surface of the housing at point *r* (Fig. 3) and be deflected upward into the hopper, thus causing the spitting back.

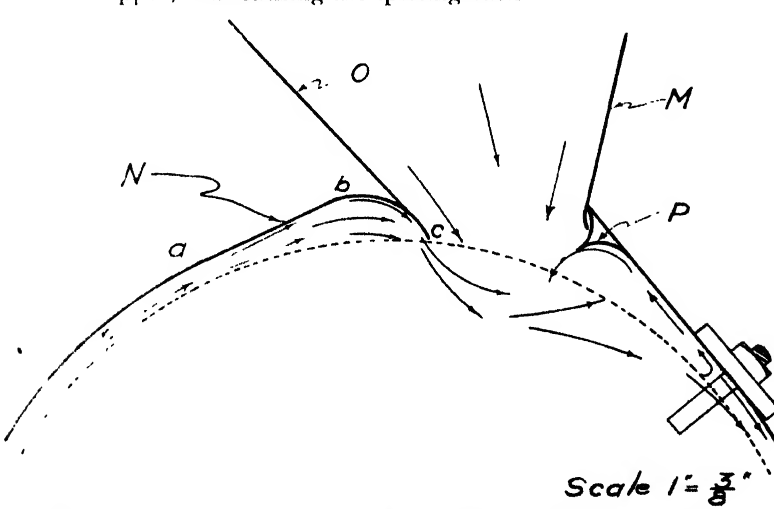

FIG. 4.—The air currents controlled by the special devices *N* and *P*.

Fig. 4 shows by arrows how the metal piece *N* controls the air currents. The straight portion *a b* is half the total length *a c*, and *b c* has a radius of curvature equal to half the length *a b*. Between point *c* and the path of the cylinder teeth there is very little clearance. The straight portion *a b*, which is tangent to the curve of the cylinder housing at *a*, permits a free movement of air off the cylinder in a natural direction with minimum loss of velocity. After the air passes the point *b*, the curve *b c* changes the direction of the air current and reduces its velocity. The convergence of the air just beneath point *b* and its constriction at point *o* increases the velocity considerably, which more than counterbalances the reduction of velocity by the change in direction. The air is directed downward into the cylinder, and with increased velocity it has sufficient momentum to remain in the cylinder long enough to travel some distance. Meanwhile, an appreciable suction is produced in the space between points *c* and *P*. Although the centrifugal force of the revolving cylinder pulls the air current back to the outer portion, enough distance has been covered to pass the opening of the hopper *M* with no air escaping upward into the hopper. The metal piece *P*, functioning on the same principle as that of *N*, redirects the eddy air current produced by the concave teeth, otherwise the air would rush up the plane *O*. Because of the appreciable suction at the base of this plane, there is a downward movement of air along the plane *O*, which aids considerably in cleaning the walls of the hopper.

The bottom area of the tray *S* (Fig. 2) is large enough to accommodate a maximum quantity of threshed material in a very thin layer. This thin layer facilitates removal of chaff by the air draft from the cylinder passing over it. The length of the tray is sufficient to form an opening *W* at one end while the other end is closed. At the time the sheaf of grain is inserted into the machine, the opening at the rear end of the tray permits the circulating chaff to escape. After the heads are threshed, the tray is pulled out far enough to close the rear opening and at the same time open the front for further cleaning of the grain. Any remaining foreign material may be removed by tapping beneath the tray.

The amount of effective windage is regulated in four ways, namely, by the fans on the cylinder, by the shutters over the holes *Z*, by the adjustment of the wind restrictor *R* located just above the tray, and by the speed of the cylinder.

The cylinder *A* (Fig. 2), the only moving part of the thresher, is made from a 7-inch engine pulley 4 inches across the face. The teeth are made from quarter inch bolts fastened to the face of the pulley, measuring 11 inches between the tips of the opposite sets. *D* and *X* are two sets of fans held in place by the cylinder teeth. Concave teeth *K* are quarter inch bolts screwed into the steel bar *L* and locked by nuts on the back. The bar is bolted to the oak disk *H*. The parts made from 18-gauge sheet metal are the cylinder housing *H* and *J* reinforced with oak disks, the feeder hopper *N*, the sloping plane *O*, the wind director *N*, and the metal piece *P*.

The other parts made from 20-gauge sheet metal are the grain catching device *Q* and the tray *S*. The tray is 8 x 9 inches and 2½

inches deep. The four legs *U* have lugs at the base by which the machine is fastened firmly to a wooden floor with lag screws.

The total cost of material in this thresher at retail prices was less than $25.00. Some second-hand parts were used. Very little power is required for operation. A 1½ H. P. gasoline engine gave more than adequate power for any operating condition.

The capacity of the machine is sufficient to handle rod rows with a maximum yield of approximately 17 bushels per acre. A machine with a larger capacity can be constructed by widening the cylinder and enlarging the bottom area of the tray.—H. D. JACQUOT, *Adams Branch Station, Lind, Wash.*

WASHING AND HALVING SUGAR BEETS PREPARATORY TO SUGAR AND PURITY DETERMINATIONS

In the preparation of samples of sugar beets for a determination of their quality by chemical analyses, it is often necessary to wash the beets composing the samples free from soil and to cut each beet longitudinally into halves in order to provide two comparable sub-samples for parallel determinations. At the Michigan Agricultural Experiment Station two machines have been built which materially reduce the amount of labor involved. One machine washes the samples and the other saws the individual beets into halves. With these machines the work of washing and halving the beets has been speeded up materially and operating costs have been reduced to a minimum.

THE WASHER

As shown in Fig. 1, the washing machine consists of a basket set in a rack on the end of an inclined, revolving shaft. The base of this shaft is set on a thrust bearing. As the basket turns, the beets in the sample are rolled one over the other, exposing all parts of the roots to the action of the water jets. The nozzles through which the water is admitted to the machine are mounted on the inside of the galvanized cover and are quite close to the beet roots when the cover is closed. Because the water is admitted under high pressure, the basket is inclosed in a galvanized iron tank to confine the spray. An outlet for the water is provided at the bottom of the tank.

Power for turning the basket is secured from a ¼ H. P. motor operating at 1,700 R. P. M. The first reduction in speed is secured by running the belt from the 1½ inch pulley to a 22-inch pulley mounted on the side of the machine. A second reduction in speed is secured in the bevel gears between the jack shaft and the inclined shaft. These bevel gears were secured from the differential of a Model T Ford rear axle. With this reduction in speed, the basket revolves about 40 times a minute.

For convenience in operating, the switch for starting the motor is placed within reach of the operator when standing in front of the machine and the quick closing valve controlling the water supply is mounted on the outside of the cover. The water supply is carried to the machine through a pressure hose.

In actual operation samples consisting of 20 beets with a large amount of adhering soil were washed sufficiently clean for use in 45

seconds. Not more than 15 seconds were necessary to change the samples in the machine so the capacity of the washer is practically a sample a minute during operation.

With the experience that has come from constructing and operating this washer, two or three observations can be made concerning advantageous changes. A ½ H. P. motor would be better, as the ¼ H. P. motor was overloaded. The standard 2-bushel baskets in which the beet samples were washed are 20.5 inches in diameter and 16

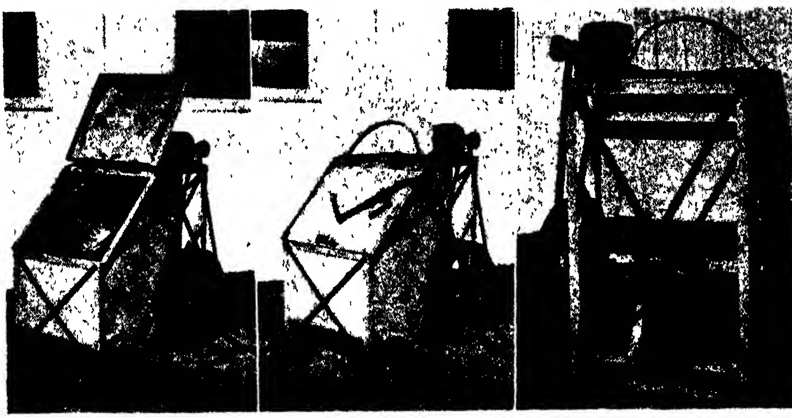

FIG. 1.—Construction details of the beet sample washing machine. The basket shown in the machine revolves upon an inclined axis. When the cover is closed the nozzles shown on the inside of the cover are very close to the beet roots. View C shows the rear of the machine, with the arrangement for reducing speed.

inches deep. These baskets should have been at least 30 inches in diameter for the best results, for with extra large beets or samples consisting of 30 or more beets the 2-bushel baskets proved to be a little too small. At least 4 inches should be allowed between the edges of the basket and the sides of the tank in place of the 2 inches allowed in this machine. The number of nozzles could be doubled and water direct from the mains under ordinary pressure could be used with equally good results.

The overall dimensions of this machine are height, 40 inches; length, 40 inches; and width 25 inches. The opening is 25 inches square. The frame was made of 1½ by ⅛ angle iron, 5/16 by 1 inch flat iron, and 28 gauge sheet metal was used in the construction of the tank. If larger baskets are used, a frame several inches larger than the one for this machine would be necessary. The special articles used in the construction are:

1 ¼ H. P. electric motor, with 1½ inch pulley
1 22-inch pulley
3 "Chicago" shower bath heads
4 common flat boxes—two for the jack shaft and two for the inclined shaft
1 thrust bearing for base of inclined shaft
1 quick-closing valve

THE BEET SAW

In preparing sugar beets for analysis, the sample roots were cut longitudinally in half by means of an 18 inch circular saw (Fig. 2). This saw was mounted in a frame and operated by a 1/6 H. P. motor at approximately 1,000 R. P. M. The saw was mounted so that the lower edge practically reached the bottom of an inclined right-angled trough in which the beets were placed. The frame for this machine was constructed of 2-inch by ⅛ angle iron. The trough was formed by bolting two pieces of 16 gauge metal to the inside of a piece of angle iron. The overall size of the frame is 60 inches long, 30 inches wide, and 40 inches high.

FIG. 2.—Construction and arrangement of the circular saw, used in sawing the roots of the sugar beets.

In operation the beets were placed tip first in the trough and given a slight push. As the trough soon became wet, very little difficulty was experienced in having the beets stop before reaching the saw. After the beets reached the saw they would move forward at approximately the same rate that they had slid down the trough until the saw had cut nearly through the root. When a sufficient cut had been made to allow the two halves to drop towards each other, the halves would drop in against the saw, greater friction would be created, the remainder of the cut would be made very quickly, and the halves would be expelled from the trough with considerable force. This necessitated the construction of special guards to stop the halves and drop them into the proper baskets or crates.

In actual operation 30 seconds sufficed for the halving of the 20 beets in a sample. As practically half a minute was used in delivering the halved sample to the next machines and in securing the next sample to be halved, the capacity of the machine is practically one sample per minute, the same as the washer.

With the experience that has come from constructing and operating this beet saw, two changes would appear to be advisable. The motor used to operate this machine should be ¼ H. P. as the 1/6 H. P. motor was over-loaded. The guards placed to guide the beet halves into the proper baskets or crates should be carefully and strongly constructed as the beet halves are expelled from the machine with sufficient force to carry them several feet unless stopped by the guards. These guards should be so formed that the beet halves can drop no place but into the desired basket or crate.

The special items used in the construction of this machine were:

1 18-inch circular rip saw
1 cold-rolled shaft, 30 inches long
1 1/6 H. P. motor with 1½-inch pulley
1 3-inch pulley
2 common flat boxes

Fig. 2 shows the construction of the saw frame.—J. G. Lill, *Michigan Agricultural Experiment Station, East Lansing, Mich.*

BOOK REVIEWS

PRACTICAL HANDBOOK OF WATER SUPPLY

By Frank Dixey. London: Thomas Murby & Co. XXVIII+571 pages, illus. 1931. $8.50.

This book is an exhaustive treatise on the water supply of the British dependencies of Southern, Central, and Eastern Africa. There is a detailed discussion of the different sources of surface water supply and various means of utilizing water from these sources. Certain of these sources are decidedly unusual and illustrate the extremes to which natives of dry regions find it necessary to go to find water for drinking and other purposes.

Groundwater is discussed in some detail. Attention is paid to the effects of meteoric and plutonic waters, evaporation, run-off, soil absorption, erosion, transpiration, forests, and the character of rocks and rock structures on the water table and the supply of ground water. The quality of water with regard to dissolved salts, silt, and organic impurities is given consideration, as well as methods of examination and purification of water and safeguarding the water supply.

Scientific methods of locating underground water supplies are thoroughly discussed and contrasted with the hit-and-miss method of locating water with the divining rod. The book also includes a chapter on the recovery of groundwater which goes into considerable detail concerning the various methods of sinking wells, preparing them for use, and maintaining them under different conditions of soil and rock through which the wells are constructed.

This book is of special interest to agricultural workers in arid and semi-arid regions where it is difficult to secure supplies of water for home use, livestock, and crops. The observations concerning the effects of the improper cultivation of hillside farms on erosion and water supply are also of considerable interest to agronomists.

(W. B. C.)

PRINCIPLES OF SOIL MICROBIOLOGY

By S. A. Waksman. Baltimore: Williams and Wilkins Co. Ed. 2, revised, XXVIII+894 pages, illus. 1932. $10.00.

The first edition of this book (1927) is well known and has proved itself a useful reference book to the soil biologist. The present corrected and revised edition should be still more useful. The book covers a wide field in such detail that mistakes are inevitable and in the first edition were not to be regarded too critically. It is plain, moreover, that the author plans to eliminate such errors and keep the book up to date by revision of successive editions. Many such corrections have been made in this edition.

The new preface states, "The book has been brought up to date by the incorporation of the additional information. A number of chapters have been entirely rewritten, especially those dealing with the mycorrhiza fungi and the soil as a medium for plant and animal parasites. A number of new chapters have been added, dealing with

the rôle of micro-organisms in the decomposition of organic matter in green manures and stable manures, in the formation and decomposition of peat and forest soils, and with the relation between plant growth and the activities of micro-organisms in soil. To avoid any considerable increase in the actual size of the book, a certain amount of condensation became necessary so as to balance the added material. This was accomplished by leaving out some of the text which did not bear directly upon the subject under consideration. Several chapters have been combined so as to avoid unnecessary duplication."

The new edition contains actually about 15 fewer pages of text than the first. The number of figures, however, has been increased from 77 to 83, the number of tables from 93 to 108. Three full-page plates have been eliminated, two of them unfortunately the portraits of Dr. Beijerinck and Dr. Winogradski, each splendid in itself but perhaps unnecessary for the scientific treatment of the subject matter. One plate, illustrating photo-micrographs of micro-organisms in soil, has been replaced by an entirely new one, made up largely of photomicrographs on the same subject recently published elsewhere by Cholodny This change is significant as it shows the author's recognition of the important contributions of Cholodny to the direct study of the microflora of soil.

The new edition can unquestionably be considered as much more valuable than the first. (H. J. C.)

CONTRIBUTIONS OF THE UKRAINIAN INSTITUTE FOR SOIL RESEARCH

Edited by A. N. Sokolovsky; translated by A. A. Plestcheeva and A. A. Abramov. Kharkov: Derdzsilhospvidav. 202 pages, illus. 1931.

This volume, the third in the series of contributions from the Ukrainian Institute for Soil Research, is edited "in honor of the second International Congress of Soil Science" and contains ten titles, as follows:

Geomorphological and Geological Characteristics of Ukraine, by V. I. Krokos; General Characteristics of the Ukrainian Vegetation, by E. M. Lavrenko; Soils of the Steppe and the Donetz Basin, by G. G. Makhov; An Uninterrupted Method Suggested for Determining the Mechanical Composition of Soils, by M. M. Godlin; Suggested Method of Determining the Na Absorbed by the Soil, by M. M. Godlin; The Part of the Ukrainian Pedologists in Highway Research, by S. M. Muravliansky; A Rational Nomenclature of General Horizons in Soils, by A. N. Sokolovsky; Agricultural Characteristics of Soils in Ukraine, by A. N. Sokolovsky; Main Regions of Melioration in Ukraine, by T. V. Sekunda; and The Problem of Soil Structure, by A. N. Sokolovsky. In addition there are brief notes on soil investigations under way at experiment stations, special institutes, and agricultural colleges in Ukraine. (J. D. L.)

AGRONOMIC AFFAIRS

AUTHOR ABSTRACTS

Upon the request of Dr. J. R. Schramm, Editor of BIOLOGICAL ABSTRACTS, an effort will be made to supply him with author abstracts of all articles appearing in this JOURNAL, which fall within the scope of BIOLOGICAL ABSTRACTS, beginning with the May number. Forms for that purpose have been supplied by Dr. Schramm and hereafter will be attached to galley proof mailed to authors. The forms ask for brief abstracts prepared by the author for publication in BIOLOGICAL ABSTRACTS and indicate the general style to be followed. The abstracts are to be returned to the Editor of the JOURNAL with the corrected proof. The Editor will see that the abstracts are forwarded to Dr. Schramm in proper order as the articles appear in the JOURNAL.

The success of this undertaking will depend very largely upon the full cooperation of the authors, and it is earnestly commended to their careful consideration. The advantages of adequate author abstracts from the standpoint of BIOLOGICAL ABSTRACTS, this JOURNAL, and the author are obvious.

"BIOINTIZATION"

The above term has been coined in Russia to denote the preliminary treatment of seed with chemicals to stimulate growth, according to J. W. Pincus, consulting agriculturist of New York City. The Lenin Academy of Agricultural Sciences maintains a special laboratory for the study of this problem and has announced the following results:

"Biointizators" developed for wheat and designated as Nos. B74, B84, and B110 have increased yields by 19%, 26%, and 41%, respectively, at the Saratov Grain Institute. With corn, B74 and B84 gave increases of 38% and 51%, respectively, at the Samarkand Experiment Station. Yields of peas were increased by 18%, 23%, 26%, and 34% by treating the seed with BXY, B74, B84, and B110, respectively. With beets, BXXX and IV have given increases of 30% and 40%, respectively. The treated seed are also said to have transferred this stimulation to their offspring. Furthemore, a new and superior variety of cotton called "Stalin's Bouquet" has been produced with a biointizator by treating the variety Novrotzky.

Many Russian experiment stations report that in addition to stimulating and "improving the quality" of the seed, the biointizators also have some fungicidal effects. The cost of the treatment is said to average about 25 cents per acre.

SOYBEANS IN RUSSIA

We are also indebted to Mr. Pincus for a note on a special soybean institute set up by the Lenin Academy of Agricultural Sciences with laboratories in Moscow and Kharkov. Breeding work with American,

Manchurian, and native varieties is in progress at several stations in northern Caucasus, Ukraine, and central Asia.

Soybeans varieties are being studied with reference to their oil content, their adaptability for use as coffee substitutes, and their use for human consumption. Factories are also being established for the production of soybean "casein" and soybean "milk".

NEWS ITEMS

T. C. JOHNSON, for many years Director of the Virginia Truck Experiment Station at Norfolk, died on March 31, following a brief illness.

ON APRIL 8, the Board of Trustees of Massachusetts State College accepted the resignation of Dr. R. W. Thatcher as President, effective September 1, and immediately tendered him an appointment as Research Professor in the Massachusetts Agricultural Experiment Station. Continued ill health forced Dr. Thatcher to relinquish the responsibilities and duties of the President's office. His appointment to the Experiment Station staff will take effect early in 1933, following a vacation and rest.

DR. R. A. EMERSON, Head of the Department of Plant Breeding in the College of Agriculture, Cornell University, Ithaca, New York, gave the third series of annual lectures under the Frank Azor Spragg Memorial Fund, April 5 to 8, at Michigan State College. This memorial is in honor of Professor F. A. Spragg who was in charge of plant breeding work at the Michigan Agricultural Experiment Station from 1906 until his death in 1924. Dr Emerson's subjects were as follows: Cooperation in Plant Breeding; Heredity and Environment (a non-technical lecture); Breeding White Beans for Disease Resistance, Yield, and Canning Qualities; The Present Status of Corn Genetics and Cytology; and The Solving of a Genetics Problem—The Inheritance of Variegated Pericarp in Corn

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EFFECT OF SOIL REACTION ON THE EARLY GROWTH OF CERTAIN CONIFEROUS SEEDLINGS[1]

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Soil acidity as affecting germination, growth, and development of plants has received considerable attention in recent years. These studies have dealt with many phases of the problem, from the effect of hydrogen and hydroxyl ions on the growth of plants to the indirect effect of the concentration of these ions on the toxicity of or deficiency of certain elements. The influence of soil acidity has been ascribed to several causes, the most important of which are effect on supply of available calcium needed by plants in the manufacture of plant foods, influence on the symbiotic nitrogen-fixing bacteria, toxic or destructive effect on root tissues, and prevention of plants from getting at a sufficiently rapid rate the calcium needed to precipitate acids formed in them.

REVIEW OF LITERATURE

Comparatively little work has been done to determine the effect of hydrogen-ion concentration on seed germination and the growth and development of forest tree seedlings. What literature is available indicates that soil acidity may be a limiting factor in forest tree nursery work and in the establishment of seedlings in the forest.

Baldwin (7)[3] found that Norway spruce (*Picea excelsa*) seed apparently germinated better in soils having a higher hydrogen-ion concentration than in more alkaline soils. Toumey and Li (8) found that

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[3]Reference by number is to "Literature Cited," p. 351.

the effect of soil treatment by acids influenced tree seed germination and that the response varied with the different species. They found that the application of formalin hastened germination, while germination was delayed by acid treatment. They also found that the root development in seedlings was impaired, a fewer number of laterals being produced and those that were produced being stunted.

Salter and McIlvaine (3) have shown that the seeds of wheat, corn, soybeans, alfalfa, and barley germinate the best in a medium having pH values between 7.71 and 2.96, a slightly acid reaction being favorable in all cases.

Wherry (6) cites Aaltonen as finding that the maximum germination of scotch pine (*Pinus sylvestris*) occurred at a pH of 6, of Norway spruce at a pH of between 4 and 5, and of birch (*Betula verrucosa*) and alder (*Alnus incona*) at a pH of 4.

Moore (9) applied slaked lime to a mixture of sand and humus and found that the root development of certain coniferous seedlings was distinctly affected. Abnormal root development occurred, and the seedlings were unhealthy. Of the various species worked with, cedar (*Juniperus virginiana*) and jack pine (*Pinus divaricata*) were found to be the least affected by the lime treatments.

Melin (11) found that mycorrhizal growth on pine and fir seedlings varied with soil acidity, the poorest growth being produced at a pH of 3.5 and a pH of 7, with an optimum at about a pH of 5 or a little lower.

Wherry (5), reporting on the work of Mevins, states that it is clearly shown that the hydrogen-ion concentration of the medium is of the greatest importance in the growth of plants from the lowest to the highest.

The effect of hydrogen-ion concentration on the metabolism of plants has been studied by Truog (1) who assumes that a lack of available bases, especially calcium, is of great importance in acid soils.

Truog and Meacham (2) have shown that the juices of different species of plants vary considerably in their acidity and that bases are needed in the formation of buffer solutions which stabilize this acidity.

Hesselman (13) found that reaction values and available nitrogen in soils are very closely connected. He also found that height growth of coniferous seedlings was independent of the hydrogen-ion concentration variations through the variation scope of the soils with which he worked. Only to the degree in which acidity favorably influenced nitrification could height growth responses be noted.

Tarr (10) used a calcium chloride solution of varying concentration and acidity and noted the effects of this solution on root growth and

development. His work showed that acid and alkaline reactions give typical root forms.

Wherry (14), in a study of 23 eastern conifers, found that more than half of them preferred acid soils. Among these were jack pine, red spruce (*Picea rubens*), red pine (*Pinus resinosa*), and white pine (*P. strobus*).

Kelly (15) found pitch pine (*Pinus rigida*) forests occurring along the New Jersey coast in localities where the pH values of the surface soil ranged from 5.2 to 5.6. This species did not, however, occur on the more alkaline soils near the shore.

Moore (9) found that root growth of coniferous seedlings was very noticeably affected by the addition of lime to a soil. He found that the growing tip of the root became brown and shriveled, sometimes for its entire length, and that often the root would be abnormally twisted and in many cases the upper part came out of the ground, lying on the surface.

Farr (10) describes different form changes of roots and causal effects, stating that form changes of roots, although not readily measured, constitute the most conspicuous reaction of the root to changes in soil solution.

Wherry (14) studied jack pine in the sand dune region of northern Indiana in an area of glacial drift, rich in grains of limestone, and found that the seeds of the species germinated in this soil, which had a neutral reaction. He lists red pine as preferring acid to intermediate habitats. He (5) quotes Aaltonen as giving the maximum germination of Norway spruce between pH's of 4 to 5.

Many workers have contributed to the literature on soil acidity or alkalinity and the effect of hydrogen-ion concentration on seed germination, seedling growth, and development. No negative results are reported and only in a few instances are indefinite conclusions drawn.

Whether hydrogen-ion concentration is of primary or secondary importance is still a question. The fact remains that a knowledge of pH values may be of decided importance in answering questions relating to plant growth.

PROCEDURE

The work reported on in this paper was suggested by noting pronounced variation in coniferous seedling growth and survival in a large forest tree nursery. In comparing seedlings from this nursery with those of other nurseries, it was apparent that they were inferior in both size and thriftiness. These comparisons, however, were not applicable to transplant stock. The soil on which the nursery had

been established was a Wheeling silt loam (16). It had produced excellent field crops prior to establishment of the nursery. Liming had been regularly practised, and at the time this experiment was initiated pH values ranged from 6.2 to about 6.8 throughout the nursery. Seedbeds were spotty, ranging from areas on which very poor seedlings or no seedlings were growing to areas where comparatively normal nursery stock was produced. In all cases the best seedlings were found on areas where the soil was most acid.

In order to check more carefully and to offer comparison, it was decided to work with two soils beside the Wheeling silt loam taken from the nursery. These other soils were a Morrison sand (17) and a Hagerstown silty clay loam (17). Work with the Morrison and Wheeling soils was done under greenhouse conditions, while with the Hagerstown soil the work was done out-of-doors in the Pennsylvania State College Forest School Nursery, offering a comparison with the forest tree nursery on the Wheeling soil.

The greenhouse set-ups were carried through two winters, and each series was run in triplicate. The plats on the Hagerstown silty clay loam were run through one growing season and all set-ups were made in duplicate. Comparable conditions were maintained in all pots and plats throughout the experiment in so far as possible. Flour of sulfur was used to obtain acid conditions and air-slaked lime to produce alkaline reactions. Reaction values were established colorimetrically and electrometrically in most cases. The data are based on average weight values, averages being confined to values falling within 1.0 pH.

The greenhouse work was conducted in gallon crocks holding from 3,000 to 4,000 grams of air-dried soil. From 1 to 15 grams of sulfur were used to obtain more acid conditions than that of the check pots, and from 2 to 20 grams of air-slaked lime to secure less acid and alkaline mediums. After adding the varying amounts of sulfur and lime and working these thoroughly into the soil by hand, the crocks were allowed to stand for 2½ weeks, maintaining optimum moisture conditions. This aided in permitting the soil solution to reach an equilibrium before seeds were planted.

The pots were weighed regularly and kept at optimum moisture conditions throughout the experiment. To permit bottom watering and to allow for aeration, a bent glass tube was placed in each crock with one end on the bottom of the crock and covered with paper to keep the soil out and permit the ready flow of water.

Repeated sampling during the course of the experiments showed that the sulfur-treated pots in the Morrison sand became slightly more acid, the check pots slightly less acid, while some of the pots

treated with lime tended to become less alkaline and others remained about the same. In the first experiment conducted with this soil the change was much less than in the second experiment, which ran twice as long. The Wheeling silt loam did not show as great a change as did the Morrison sand, some of the pots maintaining the same pH values throughout.

At the time the set-ups were torn down and seedling measurements made pH values were determined at both the top and bottom of each crock. It was found that the surface soil in all pots of the Morrison series was more alkaline than the soil in the bottom of the pots. This difference varied from 0.1 to 0.3 pH the first year and as much as 1 pH the second year. In the case of the Wheeling loam greater stability was apparent, and where changes had occurred, they were just opposite those of the Morrison loam. The greatest variation occurred in the more alkaline pots, which, at the close of the experiment, showed the surface soil to have a more acid reaction by 0.5 pH than the soil from the bottom of the crocks.

Four species of conifers were used throughout the experiments. They were white pine, jack pine, red pine, and Norway spruce. Due to failure of the jack pine to germinate well or to withstand damping-off in the Wheeling loam, no data on this species are given for this soil.

Fifteen seeds of each species were planted to each pot. It was anticipated that 10 seedlings of each species would be maintained in each pot, but due to unavoidable losses less than this number were available for measurement in some instances. The first series (1927–28) ran for 3 months and 10 days, while the second series ran for 6½ months. The measurements taken of the various seedlings consisted of total lengths, root length, stem length, total number of laterals, and number of laterals over ½, 2, and 5 cm in length.

Observations were made on the color of roots and abnormalities of any kind in the top or roots. Due to delayed germination of some of the white pine and Norway spruce seeds, it is felt that the data presented are not as conclusive as the data secured on the jack pine and red pine.

MORRISON SAND EXPERIMENT

The soil used in this experiment was taken 6 inches from the surface after the litter and humus had been raked away. A typical leached horizon was present. The soil was thoroughly mixed before potting to insure uniformity. Ten series of gallon crocks were set up in triplicate with pH values ranging from 1.5 to 8.2, including the check pots which had pH values of 4.8. The results of these two series are presented in Tables 1 and 2.

The data secured from the Morrison sand experiment indicate that the optimum acidity for good growth and development in this soil lies between pH values of 5 and 6. The species vary in many respects. The best responses were noted in the case of the jack and red pine. Root deformation and coloration were particularly noticeable in the very acid or alkaline pots. The capitate form of root hair was observed in the most alkaline pots as well as the many-branched and curved form of root growth. Seedlings growing in the very acid pots had dark brown roots and the ends of the roots in most instances were burned back.

WHEELING SILT LOAM SOIL

The soil used in this series was obtained from the forest tree nursery previously mentioned. Sampling indicated a pH variance from about 6.2 to 6.8, with 6.6 to 6.8 being the more common values obtained. Samples were taken from areas where values of 6.2 were found. Thorough mixing insured uniformity. The set-ups were the same as in the previous experiment. Due to the high silt content of this soil, it was extremely difficult to work with in pots. Top watering tended to produce caking, and rapid drying out of the surface soil produced cracks.

The results obtained with this soil are given in Tables 3 and 4. Jack pine responded to an acid media and the largest seedling was produced at a pH of 3.6. The best red pine seedlings were found in the pots having a pH of 3.6; the longest seedlings were found in pots whose soil had reaction values of 4.8 to 7.4. Norway spruce responded best when distinct acidity was present, the largest seedlings being found in the pots whose pH was 4.1.

From this work it is apparent that the Wheeling loam which was used in these experiments is decidedly too alkaline for good seedling development. Field investigations showed that the poorest seedlings were found on the most alkaline areas, and the results of the pot work verified this. In this instance the use of lime was unnecessary, in fact it produced an alkaline soil unfavorable to coniferous development.

HAGERSTOWN SILT LOAM

The work in connection with this series was carried on in the forest school nursery. The soil was a Hagerstown silty clay loam which had been used for over 15 years for lining out and transplanting without fertilization.

A series of beds 4 feet wide were constructed and divided into compartments 18 inches wide. Each compartment was given a lime or sulfur treatment. These chemicals were thoroughly worked into the

TABLE 1.—*Results on Morrison sand, series No. 1.*

	Average pH values in series															
	Jack pine				Red pine				White pine				Norway spruce			
	4.9	5.8	7.1	8.1	4.9	5.8	7.1	8.1	4.9	5.8	7.1	8.1	4.9	5.8	7.1	8.1
Germination, %	37	76	86	62	76	84	83	59	21	20	11	14	39	43	40	39
Av. length seedlings, cm	17.5	20.2	16.5	9.2	14.1	16.0	14.1	8.1	14.1	11.6	11.6	10.0	13.6	12.7	13.0	8.2
Av. length tops, including hypocotyl, cm	7.1	6.2	5.3	3.7	5.5	5.6	4.7	4.0	5.8	5.4	4.8	5.2	4.2	4.6	4.3	3.7
Av. length tap root, cm	10.8	14.0	11.9	4.2	9.1	10.6	9.0	4.3	8.8	6.1	6.5	4.7	9.0	8.1	8.5	4.5
Av. No. lateral roots	28.3	42.0	44.3	17.0	19.0	20.3	19.5	6.6	10.3	7.0	8.0	3.6	28.6	23.5	29.0	14.6
Av. No. lateral roots over ½ cm in length	7.8	8.5	9.0	2.4	6.4	5.9	5.2	1.0	4.0	1.5	1.2	0.5	4.3	6.2	9.0	3.0
Av. No. lateral roots over 5 cm in length	2.1	2.0	1.2	0.1	0.8	1.0	0.6	0.0	1.0	3.0	1.0	0.0	0.2	0.2	0.3	0.0

TABLE 2.—*Results on Morrison sand, series No. 2.*

	Average pH values in series																							
	Jack pine						Red pine						White pine						Norway spruce					
	4.3	4.9	5.6	6.4	7.0	7.7	4.3	4.9	5.6	6.4	7.0	7.7	4.3	4.9	5.6	6.4	7.0	7.7	4.3	4.9	5.6	6.4	7.0	7.7
Av. length seedlings, cm	18.2	17.2	18.8	14.0	13.5	13.6	18.6	18.4	18.8	18.0	15.6	10.0	11.4	12.4	13.2	14.8	13.7	11.6	13.4	16.4	15.8	14.5	12.0	14.0
Av. No. laterals over ½ cm long	7.8	6.6	6.2	4.4	3.0	2.6	8.8	8.6	8.2	7.2	4.1	2.9	4.8	3.7	4.0	2.4	2.2	1.2	9.8	8.0	11.0	7.8	7.3	6.8
Av. No. laterals over 2 cm long	3.3	4.3	3.6	1.6	0.6	1.0	3.3	4.3	3.4	2.3	0.8	1.0	0.4	0.8	1.6	0.7	2.2	1.3	2.7	2.8	3.9	3.1	2.7	2.4
Av. No. laterals over 5 cm long	1.3	2.2	1.6	0.4	0.2	0.3	0.9	1.5	1.0	0.8	0.0	0.5	0.0	0.2	0.3	0.0	0.0	0.0	0.1	0.5	0.7	0.3	0.3	0.4
Av. weight seedlings, mgm	3.9	3.8	3.1	1.7	1.2	1.0	4.0	3.5	3.1	2.7	2.1	2.1	4.1	2.9	3.3	2.8	2.5	2.3	2.5	2.9	3.5	2.7	2.2	2.1
Av. length top, including hypocotyl, cm	4.9	5.2	5.5	4.7	4.0	4.1	5.6	5.6	5.7	5.2	5.3	5.0	5.5	5.6	5.9	5.9	5.3	5.3	4.8	5.1	5.0	4.8	4.7	4.7

TABLE 3.—*Results on Wheeling loam, series No. 3.*

	Average pH values in series																	
	Jack Pine						Red pine						Norway spruce					
	2.9	3.6	4.1	4.8	6.2	7.4	2.9	3.6	4.1	4.8	6.2	7.4	2.9	3.6	4.1	4.8	6.2	7.4
Av. length seedlings, cm.	9.8	13.6	13.2	11.5	10.0	10.0	8.0	11.2	11.7	12.2	12.3	12.2	8.0	8.6	9.4	7.9	9.2	7.0
Av. number laterals. . .	2.7	3.6	9.5	6.0	6.2	2.7	0.4	4.6	3.5	3.4	3.0	0.6	0.0	4.9	7.4	4.5	4.6	1.2

TABLE 4.—*Results on Wheeling loam, series No. 4.*

	Average pH values in series																							
	White pine								Red pine								Norway spruce							
	4.2	4.6	4.8	5.0	5.2	5.5	6.2	6.8	4.2	4.6	4.8	5.0	5.2	5.5	6.2	6.8	4.2	4.6	4.8	5.0	5.2	5.5	6.2	6.8
Av. length seedlings, cm	10.5	13.5	15.2	16.0	16.0	17.2	11.7	15.0	14.0	16.5	20.2	23.0	19.5	18.8	2.2	17.3	15.0	19.2	16.0	19.7	16.8	15.0	20.0	19.8
Av. length tops, cm.	5.3	6.8	5.5	5.7	5.4	5.1	4.1	4.8	4.1	4.5	5.9	6.0	5.6	5.8	5.8	5.2	3.9	4.3	4.5	4.2	4.2	4.5	4.5	4.5
Av. No. laterals over ½ cm.	5.0	1.8	3.9	2.8	2.1	2.9	0.6	1.5	5.7	6.1	6.5	7.0	5.8	5.1	5.8	5.1	7.1	5.5	2.8	1.2	2.7	3.8	3.0	5.6
Av. No. laterals over 2 cm.	2.0	0.0	1.2	1.0	0.7	0.2	0.0	0.5	1.2	2.4	1.9	3.2	1.5	1.6	2.1	1.6	1.9	0.9	1.6	0.4	1.0	0.8	0.8	1.0
Av. weight seedlings, mgm.	4.0	3.1	4.0	4.2	3.3	3.6	1.8	3.0	2.7	3.6	3.9	3.9	3.3	3.2	3.2	2.4	2.3	2.6	2.6	2.1	2.0	2.0	2.0	2.4

TABLE 5.—*Results on Hagerstown silty clay loam.*

	Average pH values in series															
	Jack pine								Red pine							
	3.9	4.4	5.4	6.3	7.1	7.6	7.9	8.2	4.1	4.5	5.4	6.3	7.1	7.5	7.9	8.2
Av. length seedlings, cm	11.3	21.4	17.8	18.9	20.6	22.0	19.7	15.6	16.7	14.6	15.2	14.9	14.4	15.6	14.5	13.1
Av. No. laterals over ½ cm.	5.2	16.8	8.7	12.0	—	11.1	9.2	8.6	14.0	9.8	8.2	8.2	—	9.2	8.2	7.6
Av. No. laterals over 2 cm	0.8	5.2	4.1	5.2	6.0	5.4	4.7	4.3	0.7	3.3	3.9	4.5	4.5	4.7	4.1	3.1
Av. No. laterals over 5 cm	0.0	1.6	1.7	2.1	3.3	1.9	1.9	1.9	0.4	1.4	1.0	1.4	2.2	2.5	1.9	1.4
	Average pH values in series															
	White pine								Norway spruce							
	4.0	4.5	5.4	6.3	7.1	7.5	7.9	8.2	4.2	4.5	5.4	6.3	7.1	7.5	7.9	8 2
Av. length seedlings, cm	12.2	15.5	13.1	12.3	13.4	14.2	15.8	13.4	7.2	10.5	12.6	13.2	14.1	4.3	14.2	14.1
Av. No. laterals over ½ cm	6.9	8.2	6.6	6.3	—	9.8	9.2	7.9	1.0	10.5	11.3	11.8	11.3	—	12.2	10.1
Av. No. laterals over 2 cm	3.2	3.5	3.2	3.7	2.9	—	3.8	2.8	2.4	—	3.3	3.9	4.2	5.0	5.8	4.8
Av. No. laterals over 5 cm	0.7	1.2	0.9	0.8	1.0	1.2	1.1	0.6	0.0	1.7	1.4	1.9	1.9	2.7	2.8	2.1

top 5 or 6 inches of soil. After wetting the soil and allowing it to settle for about 2 weeks, seeds of the four conifers were planted. A uniform stand was maintained by constant thinning and weeding during the summer of 1928. The seedlings were left in the beds during one growing season, then samples of 15 seedlings of each species, from each compartment, were removed and data on growth recorded. The data are presented in Table 5.

CONCLUSIONS

The data presented in the various tables indicate that soil acidity, either directly or indirectly, is an important factor in growth and development of coniferous seedlings.

TABLE 6.—*Optimum reaction in the various experiments for the measurements taken.*

Species	Morrison sand		Wheeling loam		Hagerstown silty clay loam, Series No. 5
	Series No. 1	Series No. 2	Series No. 3	Series No. 4	
Total Lengths, cm					
Jack pine	5.7	3.6	7.6	5.6	—
Red pine	5.7	6.2	4.1	5.6	5.0
White pine	4.9	—	7.9	6.2	5.5
Norway spruce	4.9	4.1	7.5	4.9	6.2
Total Number Lateral Rootlets or Those Over ½ cm					
Jack pine	7.1	3.7	4.3	4.3	—
Red pine	5.8	3.5	4.5	4.3	5.0
White pine	4.9	—	7.5	4.3	4.2
Norway spruce	7.1	4.0	6.2	5.6	6.8
Total Number Rootlets Over 2 cm					
Jack pine	—	—	7.2	4.9	—
Red pine	—	—	7.5	4.9	5.0
White pine	—	—	7.9	7.0	4.2
Norway spruce	—	—	7.9	5.6	4.2
Total Number Rootlets Over 5 cm					
Jack pine	4.9–5.8	—	7.1	4.9	—
Red pine	5.8	—	7.6	4.9	—
White pine	5.8	—	4.5	5.6	—
Norway spruce	7.1	—	8.0	5.6	—
Top Lengths, cm					
Jack pine	4.9	—	5.6	5.6	—
Red pine	5.6	—	5.6	5.6	5.0
White pine	4.9	—	—	5.6–6.2	4.6
Norway spruce	5.6	—	—	4.9	4.8–5.5–6.8

Table 6 summarizes the approximate pH values of the different soils used for optimum growth and development of the four conifers. The best seedling development occurred between pH values of 4 to 6, except in the Hagerstown series, where pH values around 7 showed the best seedling growth.

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KAW—A NEW ALFALFA[1]

S. C. SALMON[2]

Recent experiments and observations in Kansas and Nebraska seem to afford clear and convincing evidence of superior resistance to bacterial wilt and to low temperature of a regional strain of alfalfa imported and heretofore known as Provence (F. C. I. No. 34886). All other strains from Provence, France, so far tested by the Kansas Agricultural Experiment Station have proved decidedly inferior and Peltier and Tysdal (3)[3] have reported similar results at the Nebraska Agricultural Experiment Station. Indeed, they state that it is so different from others introduced from France that there is good reason to doubt that it was produced in that country. Recent information secured by H. L. Westover,[4] Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, indicates that this seed originally came from Turkestan, since the original lot has been found to contain Russian knapweed and camels thorn. The name Provence, therefore, seems to be distinctly misleading and it would appear desirable to give it some other designation. The name "Kaw" is suggested.

The resistance of Kaw and certain other varieties to bacterial wilt apparently was first observed at the Kansas station in the spring of 1926 (4). At that time only 5.4% of the plants of this variety were infected or had died during the preceding winter, presumably as a result of wilt infection, as compared with 24.3% for Grimm, 32.3% for Utah common, 33.8% for Dakota common, and 38.7% for one strain (Sunflower) of Kansas common, to mention only a few with which it was compared. Subsequent tests at the Kansas and Nebraska stations seem to have fully confirmed these early observations.

Grandfield (1) found only 12.7 and 10.5% of wilt infected plants in two different tests in which Kaw was artificially inoculated as compared with an average of 87.5% for four lots of Grimm, 99.4% for two lots of Utah common, and 88.2% for three lots of Kansas common, excluding one strain which in previous tests had been shown to be highly resistant to wilt.

[1]Contribution No. 206, Department of Agronomy, Kansas Agricultural Experiment Station. The data reported in this paper were secured in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for pulication, September 3, 1931.

[2]Professor of Farm Crops.

[3]Reference by number is to "Literature Cited," p. 353.

[4]Personal letter to author, August 12, 1931.

Peltier and Jensen (2) and Peltier and Tysdal (3) reported that in artificial inoculation experiments and in field observations at the Nebraska Station, this variety showed a high degree of resistance. Thus, in the artificial inoculation experiments, only 24% of Kaw were infected as compared with 91 to 97% for various lots of Grimm and from 93 to 99% for strains from various regions of France, including Provence.

Kaw is also of interest because of its resistance to low temperatures. In experiments at the Kansas Station in 1929, it survived artificial freezing better than Grimm or Ladak (4). Peltier and Tysdal (3) found it equal to Hardistan in this respect, and much superior to Grimm and various common alfalfas.

Because of lack of seed the information regarding yields is very meagre. In a 6-year test at the Kansas Station it produced slightly less than Kansas common. The seed was low in viability, and the stand in spite of thick seeding was thinner than other varieties during the earlier years and possibly less than the optimum.

Peltier and Jensen (2) have reported yields for 7 years at the Nebraska Station. It produced from a quarter to a half ton less to the acre than most other varieties in the test.

The available yield data are admittedly insufficient to determine the value of this variety. However, the rather clear superiority in resistance to low temperatures and in resistance to wilt as compared with other sorts generally grown would seem to make is especially worthy of attention by investigators interested in alfalfa production.

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STUDIES OF SOYBEANS AND OTHER GREEN MANURE CROPS FOR SUGARCANE PLANTATIONS[1]

George Arceneaux, Nelson McKaig, Jr., and I. E. Stokes[2]

The handling of leguminous crops extensively planted for green manure in rotation with sugarcane presents important agronomic problems very closely associated with sugarcane culture. In Louisiana it is customary to grow a legume crop, usually soybeans either alone or interplanted with corn, during the year intervening between the last ratoon crop of sugarcane and the succeeding plant cane crop. In some instances the stubble land is planted to corn and legumes for two consecutive years. In either case the legume crop is usually removed for hay. However, the policy of plowing under the entire legume crop grown in rotation with sugarcane has been adopted on numbers of plantations.

Preliminary field studies on legumes were conducted at the U. S. Dept. of Agriculture's Sugar Plant Field Station near Houma, La., during 1930, for the purpose of comparing the relative green-manuring value of several leguminous plants under conditions more or less typical of the section of Louisiana where sugarcane is extensively cultivated, and determining the most advantageous method of handling the soybean green manure crop under such conditions. The results given represent a single season's work only, but it is believed that the data are sufficiently valuable to justify publication at the present time.

EXPERIMENTAL METHODS

All yield data given in this report, except in the case of the newly imported legumes (Table 6), are based on results obtained on plats of appropriate size replicated 10 or 12 times and distributed over the area of the experiment in "checkerboard" fashion.

At the dates indicated the plats were harvested by digging out the plants, an attempt being made to include all roots. The adhering soil was then washed off and the plants permitted to dry in the shade for approximately 1 hour, which was sufficient for the evaporation of all adhering water, after which the plant material from each plat was weighed separately. The treatment was uniform in all cases and

[1]Contribution from the Division of Sugar Plant Investigations, U. S. Dept. of Agriculture Received for publication September 14, 1931.

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the results are therefore believed to be comparable. These results, expressed in terms of tons per acre, form the basis of averages listed in the tables as "Fresh Material at Harvest, Entire Plant." The weights of tops and roots per acre were deduced by proportioning the entire plant weight according to percentage figures for roots and tops obtained by weighing the root and top parts of plants used for analytical purposes at the time of harvest.

Samples for analysis were obtained from three to five representative plants, selected along the center row of each plat. Each plant was dug out with a shovel and both soil and plant taken to the laboratory where they were placed in a box with a fine wire-net bottom. The adhering soil was washed away with a gentle stream of water from a hose and the plants allowed to dry in the shade for 1 hour. An attempt was made to make this treatment entirely comparable to that received by the plant material from which yield data were obtained. The tops were then cut from the roots and each portion weighed. Duplicate samples, each representing the material from half the plats, were then finely chopped by hand and thoroughly mixed and quartered for analysis. This process was carried out as quickly as possible, several men being employed, so that the time between chopping and quartering rarely exceeded one hour. The portions for analysis were put in thin muslin bags previously dried and weighed, and immediately placed in a drying oven and dried at 95° C to constant weight. The dried material was ground to pass through a 2-mm sieve, again mixed, and the nitrogen determined by the Kjeldahl-Gunning method,[8] a second moisture determination being made at the same time in order to calculate the nitrogen results to a dry-weight basis. Preliminary experiments showed that very little nitrogen was lost by drying.

VARIETY AND DATE OF PLANTING TESTS

Soybeans are undoubtedly the legumes most widely grown in rotation with sugarcane in Louisiana, Biloxi and Otootan being the most popular varieties. Comparative plantings of these were made in the spring of 1930 to determine the relative merits of the two as green manure crops and the optimum time of planting each variety. The results of these tests are given in Table 1. The plants of each series of plats were harvested and analyzed when they were in full bloom, the stage generally considered optimum for turning under. The late-planted plats reached full blooming stage somewhat later than the

[8]Methods of Analysis, Assoc. Official Agr. Chem. Ed. 2. 1924. (Page 8.)

earlier planted ones, but the difference in time was not as great as the difference between the corresponding dates of planting, indicating a considerably shorter growing period for the late-planted beans. In the case of each variety a rather consistent drop was noted in yield of green and dry matter per acre with a correspondingly reduced amount of nitrogen per acre as the planting date was delayed. In the case of the Biloxi soybeans, the yields of green matter, dry matter, and nitrogen per acre in the case of the March 6 plantings were over twice as great as corresponding figures for May 15. With the Ototan variety, the differences in favor of early planting were even greater.

TABLE 1.—*Results of date of planting test with soybeans on light soil at Houma, La., 1930.*

Date planted	Date harvested	Fresh material at harvest*				
		Average yield in tons per acre†	Moisture %	Dry matter %	Nitrogen content	
					Lbs. per ton	Lbs. per acre
		Biloxi				
Mar. 6	July 28	18.95±0.32	69.24	30.76	12.90	244
Apr. 1	Aug. 19–21	14.33±0.19	71.56	28.44	10.88	156
Apr. 25	Aug. 19–21	14.22±0.22	72.56	27.44	11.58	165
May 15	Aug. 19–21	9.35±0.27	75.14	24.86	11.50	108
		Otootan				
Mar 6	July 28	17.24±0.24	70.96	29.04	10.68	184
Apr. 1	Aug. 19–21	11.32±0.31	72.68	27.32	8.60	97
Apr. 25	Aug. 19–21	11.18±0.31	72.38	27.62	10.42	116
May 15	Aug. 19–21	5.76±0.29	76.16	23.84	10.34	60

*Entire plant.
†Average of 10 replications on plats of 1/396 acre.

The yield of green and dry matter and nitrogen for each planting date was higher for the Biloxi variety than for the Otootan. The difference in nitrogen per acre between the two varieties varied from 48 to 60 pounds. These tests indicate that under the conditions of the experiments, the Biloxi variety had a considerably higher green manure value than Otootan and that with either variety early planting was preferable to late planting.

DATE OF TURNING UNDER BILOXI SOYBEANS

Table 2 summarizes the results of an experiment conducted to determine (1) the most suitable time for turning under the soybean crop as judged by the quantity of vegetable matter and nitrogen obtained; and (2) the proportionate quantities of vegetable matter and nitrogen in the tops or above-ground portion, and in the roots, or por-

tions below ground, at the different dates. The data plainly indicate that for the conditions of the experiment the period between August 1 and 15 was optimum. During that period the highest nitrogen content and approximately the highest yield of green and dry matter per acre were found. This period corresponds to the time when the plants were in full bloom.

The results obtained with the series of plats harvested on September 1 indicate a reduced nitrogen content as well as a significant reduction in green and dry matter per acre. By the time this series of plats was harvested a light infestation of soybean caterpillar (*Anticarsia gemmatalis*) had caused occasional damage which, it is believed, was partly responsible for the drop in amount of green and dry matter per acre. The observed quantity of vegetable matter composing the roots (under-ground portion) and its nitrogen content indicates that very little of the legume crop is left after the tops have been removed for hay, as is frequently done.

In pointing this out it is not our intention to condemn the practise of removing the legume for hay—that question being purely an economic one—but if this practise is followed, cognizance should be taken of the fact that no considerable quantities of either nitrogen or vegetable matter are put in the soil as a result of a soybean crop so handled, and that other sources of these essential fertility elements must be provided. As a matter of fact, it is very probable that when the vines are removed, more nitrogen is removed from the soil by the plant than is returned as a constituent of the roots and adhering nodules, hence the soil is probably poorer in plant food following removal of the hay crop than it was before the beans were planted.

DATE OF TURNING UNDER *CROTALARIA JUNCEA*

Table 3 summarizes field and laboratory tests conducted to determine the optimum time of turning under *Crotalaria juncea*, a legume which is showing considerable promise as a green manure crop in the sugarcane rotation. These experiments indicate that on August 14, or 110 days after planting, this plant had reached the most desirable stage for turning under, as judged by yields of green and dry matter and of nitrogen. Observations conducted on September 3 showed that, while there had been no considerable change in total dry matter per acre, the green weight and the nitrogen content, calculated to a green weight basis, had both fallen off. The rather striking result of this experiment is that within the comparatively short period of 110 days this vigorous legume produced over 33 tons of green matter, yielding 9½ tons of dry matter and 226 pounds of nitrogen per acre.

TABLE 2.—*Results of tests with Biloxi soybeans to determine yields of vegetable matter and nitrogen at different stages of growth, Houma, La., 1930.*

Date harvested*	Stage of growth	Fresh material at harvest, Entire plant: Average yield per acre,† tons	Moisture %	Dry matter %	Nitrogen content: Lbs. per ton	Nitrogen content: Lbs. per acre
June 15	No blooms	7.95±0.19	77.07	22.93	9.69	77
July 1	No blooms	10.80±0.38	78.19	21.81	9.72	105
July 15	Few blooms	16.41±0.24	76.10	23.90	9.75	160
Aug. 1	Full bloom	16.08±0.35	71.38	28.62	13.25	213
Aug. 15	Blooms and green pods	16.00±0.37	69.06	30.94	12.56	201
Sept. 1	Green and dry pods	12.22±0.54	67.33	32.67	11.87	145

Date harvested*	Stage of growth	Fresh material at harvest, Tops: Average yield per acre, tons	Tops: Moisture %	Tops: Dry matter %	Tops: Nitrogen content, Lbs. per ton	Tops: Nitrogen content, Lbs. per acre	Roots: Average yield per acre, tons	Roots: Moisture %	Roots: Dry matter %	Roots: Nitrogen content, Lbs. per ton	Roots: Nitrogen content, Lbs. per acre
June 15	No blooms	7.14	80.47	19.53	10.26	73	0.57	67.00	33.00	7.18	4.0
July 1	No blooms	10.01	79.12	20.88	9.92	99	0.79	66.45	33.55	7.40	6.0
July 15	Few blooms	14.81	76.98	23.02	10.08	149	1.60	67.99	32.01	6.66	11.0
Aug. 1	Full bloom	14.79	72.19	27.81	13.78	204	1.29	62.14	37.86	6.84	9.0
Aug. 15	Blooms and green pods	14.34	69.93	30.07	13.20	189	1.66	61.57	38.43	6.94	12.0
Sept. 1	Green and dry pods	11.33	67.70	32.30	12.28	139	0.89	62.61	37.39	6.44	6.0

*Planted April 2, 1930.

†Average of 12 replications on plats of 1/630 acre.

TABLE 3.—*Results of tests with Crotalaria juncea to determine yields of vegetable matter and nitrogen at different stages of growth at Houma, La., 1930.*

Date harvested*	Stage of growth	Fresh material at harvest, entire plant: Average yield per acre,† tons	Moisture %	Dry matter %	Nitrogen content: Lbs. per ton	Nitrogen content: Lbs. per acre
July 14	No blooms	18.29±0.47	76.01	23.99	6.34	116
Aug. 2	Few blooms	27.53±0.71	78.51	21.49	5.27	145
Aug. 14	Full bloom	33.81±0.57	71.89	28.11	6.68	226
Sept. 3	Blooms and green pods	29.95±0.62	69.57	30.43	5.71	171

Date harvested*	Stage of growth	Fresh material at harvest									
		Tops					Roots				
		Average yield per acre, tons	Moisture %	Dry matter %	Nitrogen content: Lbs. per ton	Nitrogen content: Lbs. per acre	Average yield per acre, tons	Moisture %	Dry matter %	Nitrogen content: Lbs per ton	Nitrogen content: Lbs. per acre
July 14	No blooms	16.04	76.50	23.50	6.74	108	2.25	72.49	27.51	3.72	8.0
Aug. 2	Few blooms	24.62	78.59	21.41	5.56	137	2.91	77.88	22.12	2.68	8.0
Aug. 14	Full bloom	29.20	71.88	28.12	7.18	210	4.61	71.93	28.07	3.44	16.0
Sept. 3	Blooms and green pods	26.60	69.37	30.63	6.02	160	3.35	71.20	28.80	3.34	11.0

*Planted April 26, 1930. †Average of 12 replications on plats of 1/630 acre.

RATE OF SEEDING SOYBEANS

Table 4 summarizes the results of tests conducted with two varieties of soybeans to determine the effect of the rate of seeding on the resultant yields of green and dry matter per acre and the nitrogen content. Each plat consisted of a single row 5¾ feet wide, ridged in the usual plantation manner, on which the beans were drilled in 3 lines 8 inches apart.

TABLE 4.—*Results of rate of planting test with soybeans at Houma, La., 1930.**

Lbs. of seed planted per acre	Fresh material at harvest†				
	Average yield per acre,‡ tons	Moisture %	Dry matter %	Nitrogen content	
				Lbs. per ton	Lbs. per acre
		Biloxi			
15	11.44±0.14	—	—	—	—
25	14.31±0.53	73.55	26.45	13.02	186
35	15.13±0.38	—	—	—	—
45	15.91±0.27	74.10	25.90	11.58	184
		Otootan			
10	7.88±0.22	77.83	22.17	9.08	72
15	8.68±0.34	—	—	—	—
20	9.52±0.34	76.85	23.15	8.68	83
25	8.58±0.18	76.36	23.64	8.22	71

*Planted April 11; harvested Aug. 6, 1930.
†Entire plant.
‡Average of 10 replications on plats of 1/484 acre.

The results of the analyses made on samples from the 15- and 35-pound rate of planting with Biloxi and the 15-pound rate with Otootan were not considered reliable due to accidental scorching of material in the drying oven and were discarded.

Biloxi gave a consistent increase in yield of green and dry matter as the rate of planting was increased from 15 to 45 pounds per acre. The greatest increase in yield between any two plantings was obtained when the quantity of seed was increased from 15 to 25 pounds, though the increase obtained when the rate was raised from 25 to 35 pounds appeared to be an economic one. The results obtained with Otootan seem to indicate that 20 pounds of seed per acre is probably the most economic quantity to plant.

The highest quantity of nitrogen per acre was obtained with the 35-pound rate for Biloxi and with the 20-pound rate for Otootan. The results of the two experiments indicate that the percentage of nitrogen in the plant decreases slightly as the rate of seeding increases.

SOYBEANS VS. *CROTALARIA JUNCEA*

In the spring of 1930, *Crotalaria juncea* and Otootan soybeans were planted on plats of 1/16 acre replicated 10 times. On July 29 field weights of total green matter (entire plant) were obtained for each of these two legumes, representative samples collected and analyzed, and the entire crop turned under. The results of these experiments are summarized in Table 5 and show that, while *C. juncea* contained a considerably lower percentage of nitrogen, the much larger yield

TABLE 5.—*Comparison of yields of fresh material and nitrogen obtained with Otootan soybeans and Crotalaria juncea at Houma, La., 1930.**

Variety	Fresh material at harvet†				
	Average yield per acre,‡ tons	Moisture %	Dry matter %	Nitrogen content	
				Lbs. per ton	Lbs. per acre
Otootan soybeans	9.71 ±0.38	77.34	22.66	11.02	107
Crotalaria juncea	19.31 ±0.29	74.44	25.56	6.72	130

*Planted April 23; harvested July 29, 1930.
†Entire plant.
‡Average of 10 replications on plats of 1/16 acre.

of green and dry matter obtained with it placed its nitrogen content per acre considerably above that of Otootan soybeans. These plats have been planted to cane and observations will be made to compare the results of each of these legumes on the following cane crop.

EXPERIMENTS WITH RECENTLY IMPORTED LEGUMES

Table 6 summarizes experiments conducted on several legumes which are widely used as green manure crops in certain tropical and subtropical regions, but which are not used in the United States. The very small quantity of seed available necessitated limiting the plantings of each variety to duplicate plats of 1/400 acre, and the yield from these small plats was used as a basis for calculating the per acre yields given in the table. The results indicate that *Cajanus indicus, Centrosema plumieri, Crotalaria anagyroides*, and *C. usaramoensis* may become useful green manure crops in the Louisiana sugarcane rotation.

SUMMARY

Experiments were conducted at the U. S. Sugar Plant Field Station, in Terribonne Parish, near Houma, La., in 1930, to determine the fresh weight, dry weight, and nitrogen content of several legume crops when planted on different dates and at different rates of seeding and harvested at varying stages of maturity. The data indicate the following:

TABLE 6.—*Comparison of yields of fresh material and nitrogen obtained with several legumes in rotation with sugarcane at Houma, La., 1930.**

Variety	Fresh material at harvest†					Remarks
	Average yield per acre,‡ tons	Moisture %	Dry matter %	Nitrogen content		
				Lbs. per ton	Lbs. per acre	
Cajanus indicus	21.86	69.00	31.00	9.66	211	Nodules few, large
Cassia hirsuta	—§	76.70	23.30	5.12	—	No nodules
Cassia leschenaultiana	1.92	70.92	29.08	8.12	16	Nodules many, small
Centrosema plumieri	9.49	78.07	21.83	10.70	102	Nodules many, small
Centrosema pubescens	3.30	65.61	34.39	14.28	47	Nodules many, small
Crotalaria anagyroides	21.37	73.73	26.27	8.18	175	Nodules many, large, and small
Crotalaria usaramoensis	19.31	73.03	26.97	11.58	224	Nodules many, small
Tephrosia candida	3.09	70.74	29.26	11.56	36	Nodules few, medium size
Tephrosia vegelii	2.45	78.43	21.57	9.36	23	Nodules many, small, and medium size
Biloxi soybeans‖	14.22	72.56	27.44	11.58	165	Nodules many, small, and medium size
Otootan soybeans‖	11.18	72.38	27.62	10.42	116	Nodules many, small, and medium size

*Planted April 29; harvested Aug. 26, 1930.
†Entire plant.
‡Average of 2 replications on plats of 1/400 acre.
§Only 2 plants germinated.
‖Planted April 25, 1930, and harvested Aug. 19–21, 1930 (Table 1)

In the sugarcane rotation, soybeans should be planted in the early spring for the best results.

Soybeans yield the maximum green matter, dry matter, and nitrogen per acre when they are in the full bloom stage. With early-planted Biloxi this stage was attained between August 1 and 15.

The Biloxi variety appears to be a better variety than Otootan for green manuring purposes.

Crotalaria juncea reached its optimum stage for turning under about 110 days after planting, this period corresponding approximately to the full bloom stage. This plant makes a very rapid and satisfactory growth.

The most satisfactory rate of planting Biloxi soybeans is from 25 to 35 pounds and for Otootan about 20 pounds per acre.

Among several legumes new to Louisiana, *Cajanus indicus, Crotalaria usaramoensis, C. anagyroides*, and *Centrosema plumieri* show promise as green manure crops.

DIFFERENTIAL RESPONSE OF CERTAIN SOIL TYPES TO APPLICATIONS OF CALCIUM ARSENATE[1]

W. R. PADEN[2]

It is generally recognized that under some conditions arsenic may be toxic to certain plants. The use of calcium arsenate dust over a period of 4 or 5 years on Norfolk fine sandy loam to control the cotton boll weevil has resulted in a marked depression in the growth of certain crops.[3] The response of other soil types to additions of arsenic is also a matter of particular interest. Believing that significant results might be secured by studying the growth response of certain crops in pot cultures to which varying amounts of calcium arsenate were added, a series of investigations were conducted with several soil types. Greenhouse pot cultures with two Piedmont soil types are reported in this article. The soil types selected are Davidson clay loam and Durham coarse sandy loam. These two soils differ widely in their physical and chemical properties. Only very small amounts of calcium arsenate had previously been used on either soil.

[1]Technical contribution No. 18 (new series) South Carolina Agricultural Experiment Station, Clemson College, S. Car. Received for publication September 12, 1931.

[2]Associate Agronomist.

[3]ALBERT, W. B., and PADEN, W. R. Calcium arsenate and unproductiveness in certain soils. Science, 73:622. 1931.

PROCEDURE

Eighty-five hundred grams of air-dried soil were placed in 2-gallon glazed pots. To pots of Davidson clay loam were added the following quantities of calcium arsenate: 0, 250, 500, 750, 1,000, 1,500, 2,000,

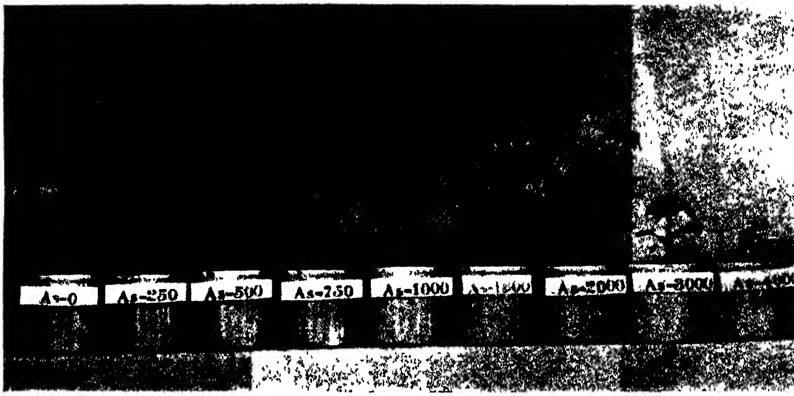

FIG. 1.—Growth of cotton on Davidson clay loam receiving various applications of calcium arsenate.

3,000, and 4,000 pounds per acre, or per 2 million pounds of soil, respectively. Quantities equivalent to 0, 50, 100, and 150 pounds per acre were added to pots of the Durham coarse sandy loam. To an

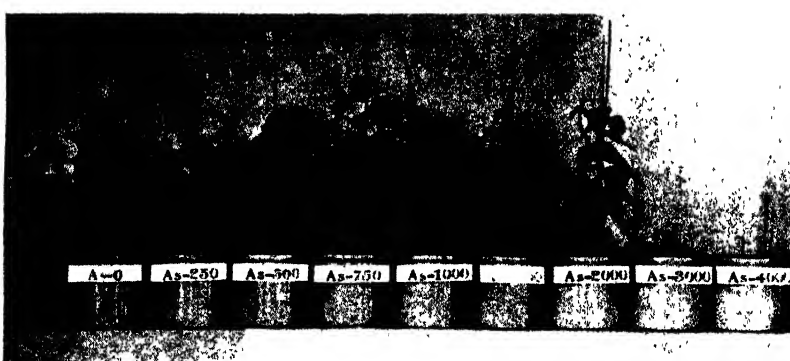

FIG. 2.—Growth of cowpeas on Davidson clay loam receiving various applications of calcium arsenate.

additional series of pots of the latter soil containing similar amounts of calcium arsenate, 600 pounds of calcium hydroxide were added to neutralize the soil acidity. Cotton and cowpeas were planted in duplicate for each treatment. One plant in each pot was allowed to grow to maturity.

EXPERIMENTAL RESULTS

The dry-weight yields from these cultures are given in Tables 1 and 2. Figs. 1 and 2 show the response of the plants to the various rates of application of calcium arsenate to Davidson clay loam. The

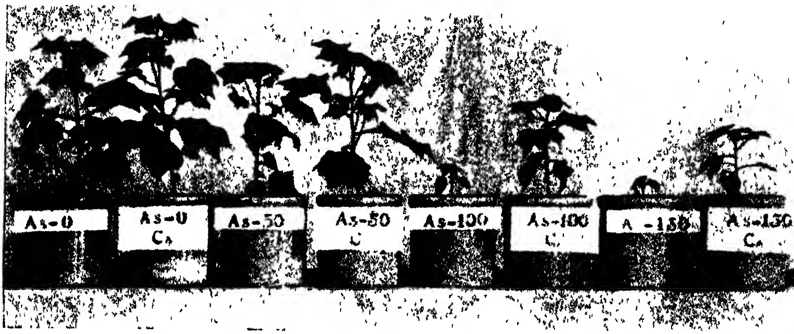

FIG. 3—Growth of cotton on Durham coarse sandy loam receiving the various applications of calcium arsenate, with and without calcium hydroxide.

response of the plants on Durham coarse sandy loam to the various rates of application of calcium arsenate and with and without calcium hydroxide is shown in Figs. 3 and 4.

It is definitely indicated that there is a marked difference between these two soil types with respect to the quantity of calcium arsenate

FIG. 4.—Growth of cowpeas on Durham coarse sandy loam with 0 and with 50 pounds of calcium arsenate per acre, with and without calcium hydroxide

required to produce injury to the growth of plants. Cotton made as much growth on the Davidson clay loam soil containing a 1,500-pound per acre application and cowpeas produced almost as much growth with a 1,000-pound application as did cotton and cowpeas grown on

TABLE 1.—*Average dry weights of two plants of cotton and cowpeas grown on Davidson clay loam with additions of calcium arsenate.*

Pounds of calcium arsenate per acre	Cotton, grams	Cowpeas, grams
0	17.60	23.85
250	20.70	24.10
500	23.85	25.00
750	18.95	21.20
1,000	17.75	17.60
1,500	15.45	11.95
2,000	8.45	11.80
3,000	2.50	0.20
4,000	0.45	0.30

TABLE 2.—*Average dry weights of two plants of cotton and cowpeas grown on Durham coarse sandy loam with additions of calcium arsenate, with and without calcium hydroxide.*

Pounds of calcium arsenate per acre	Cotton, grams		Cowpeas, grams	
	No calcium hydroxide	Calcium hydroxide	No calcium hydroxide	Calcium hydroxide
0	28.70	30.30	24.20	30.70
50	14.00	21.00	——*	2.10
100	1.50	6.20	——*	——*
150	1.10	3.00	——*	——*

*No growth.

the soil which received no calcium arsenate. In fact, there was apparently a slight stimulation in growth from the lighter applications.

The Durham coarse sandy loam was seriously injured by a light application of arsenic. An application of 100 pounds per acre almost completely inhibited the growth of cotton, and 50 pounds per acre completely inhibited the maturity of cowpeas. The additions of calcium hydroxide to the Durham soil greatly reduced the arsenic injury to cotton, however there was only slight improvement in the growth of cowpeas.

CONCLUSIONS

There was a differential growth response of cotton and cowpea plants on certain soil types to which varying amounts of calcium arsenate were added.

Knowing the response of these two widely different soil types to additions of calcium arsenate, it is possible to arrange some of the more important soils of the Piedmont section into groups according to their expected response to the additions of arsenic. Dark-colored soils may be expected to be more tolerant than light-colored soils; likewise fine-textured soils may be more tolerant than coarse-textured soils.

The data indicate that calcium hydroxide may reduce appreciably the arsenic injury on Durham soil.

THE INFLUENCE OF DATE OF PLANTING COTTON ON THE DEVELOPMENT OF ROOT-ROT[1]

B. F. DANA, H. E. REA, and HENRY DUNLAVY[2]

It has been found by investigators that the time of planting cotton influences the severity of the cotton root-rot disease, *Phymatotrichum omnivorum* (Shear) Duggar. Taubenhaus and Killough[3] planted Mebane, Bennett, and Snowflake varieties of cotton on each of four dates, *viz.*, May 6, 17, and 25, and June 7, 1921, on areas previously infected with root-rot. They reported the disease to be most extensive in the earlier plantings. McNamara and Hooton[4] observed a similar situation during 1927 when they compared cotton planted June 1 with that planted April 29. In the interest of a further study on the relation of time of planting to the development of cotton root-rot, a more extensive range of plantings was made on the Texas Agricultural Experiment Substation No. 5 at Temple, Texas, during the period of 1928–30, inclusive, the Divisions of Plant Pathology and Physiology and Agronomy cooperating.

SOIL AND CLIMATIC CONDITIONS

The cotton plantings in this test were made under conditions very favorable to the disease. The area used consisted of Houston black and Houston clay soils. Both of these soils are of heavy texture, highly calcerous, and very favorable to root-rot development. The original infection of the disease in the soils of this test was very high and well distributed as shown by the fact that nearly 100% of the cotton plants growing on this area in 1927 died from the disease. Subsequent cotton crops showed the disease to be rather uniformly distributed from plat to plat throughout the course of the experiment. Such irregularities in soil conditions as existed were largely adjusted by the placement of replications.

[1]Contribution from Department of Agronomy, Texas Agricultural Experiment Station. Technical Series No. 165. Received for publication September 24, 1931.

[2]Pathologist, Division of Horticultural Crops and Diseases, Corvallis, Ore., and Agronomist and Superintendent, Substation No. 5, Temple, Texas, respectively.

[3]TAUBENHAUS, J. J., and KILLOUGH, D. T. Texas root-rot of cotton and methods of its control. Tex. Agr. Exp. Sta. Bul. 307:1–98. 1923.

[4]MCNAMARA, H. C., and HOOTON, D. R. Studies of cotton root-rot at Greenville, Texas. U. S. D. A. Circ. 85:1–16. 1929.

Summer rainfall has previously been found by Taubenhaus and Dana[5] to influence the severity of the root-rot disease. During the growing season of 1928 the rainfall at Temple, as shown by Table 1, was sufficient to insure the continuous development of the disease. The rainfall for the last two years (1929 and 1930) was heavy at the beginning of the growing season but was low for June and July particularly. There was also a marked decrease in root-rot development compared with the preceding season.

TABLE 1.—*Precipitation at Temple, Texas, for the months of April to October, 1928 to 30.*

Year	Rainfall in inches							Year's total
	April	May	June	July	Aug.	Sept.	Oct.	
1928	2.39	0.67	3.62	5.44	1.46	3.58	0.87	29.74
1929	6.13	16.01	0.37	1.75	0.31	1.57	2.48	41.86
1930	1.24	11.23	0.35	0 21	2.55	2.79	7.18	34.75

METHODS OF CONDUCTING THE EXPERIMENT

In this study cotton plantings were made at frequent intervals throughout the optimum cotton planting period. In the vicinity of Temple this includes the months of April and May. In 1928, four plantings were made in these two months. The separate operations were accomplished on April 1 and 15, and May 1 and 15. Three plantings were within the optimum period in 1929 and were made on April 22, May 4, and May 20. The 1930 plantings were made April 10 and May 1 and 29. In addition to these dates, several out-of-season plantings were made. During the first year an extremely early planting was made on March 15 and two late dates, June 1 and 15, were used. March cotton is often damaged by low temperatures and June cotton is seldom successful due to moisture deficiencies. In 1929, a late planting was made on June 13 in order to replant a number of the May 20 plats whose stands were destroyed by heavy rains.

For each planting date throughout the 3-year period several varieties of cotton were used. Delfos, Kasch, and Bennett were used for each planting date for each year. In 1928 and 1929, Westex, Acala, Mebane, and Sunshine were also used. Westex and Delfos were selected to represent early; Sunshine, Acala, and Kasch medium; and Mebane and Bennett late-maturing varieties. In presenting the results for each year data for each variety are given to permit an analysis of the effect of earliness or lateness of planting from one vari-

[5]TAUBENHAUS, J. J., and DANA, B. F. The influence of moisture and temperature on cotton root-rot. Tex. Agr. Exp. Sta. Bul. 386:1–23. 1928.

ety to another. The data collected at each date of observation and by the end of the season were computed. From the field records of these tests Tables 2, 3, and 4 and Figs. 1, 2, and 3 have been developed. The tables present three items for each planting date and variety, *viz.*, the percentage of plants killed by the end of the growing season, the percentage killed by August 11, and the total plant population. The percentage of plants killed by August 11 is considered of special significance since plants dying prior to that date seldom mature bolls. Figs. 1, 2, and 3 present graphically the date of initial appearance of the disease and its subsequent development. The progress of the infection is charted in 25% increments.

EXPERIMENTAL RESULTS

RESULTS SECURED IN 1928

The time of first appearance of root-rot in the 1928 plats is shown in Fig. 1 for each variety and for each planting date. This line indicates the first of the bi-weekly counts at which root-rot was recorded in each case. The first occurrence of root-rot came within a very narrow range for this season. The time of first appearance of root-rot tended to be uniform for all planting dates and was subject to distinct limitations independent of the date at which the crop was planted. From variety to variety and from planting date to planting date there was some variation in the date of first appearance. It may be seen, however, that these fluctuations were compensating. Also, a consideration of the length of time intervening from planting to initial infection for the various planting dates shows that the greatest interval was obtanied for the plantings made March 15. This interval decreases progressively in length for the five subsequent plantings. Some relation of time of planting and consequent age of plant to first appearance of the disease is seen in the June 15 planting where there was a noticeable delay in initial infection. A moderate delay is also apparent in the May 15 and June 1 plantings.

The progress of the disease throughout the summer was remarkably rapid for cotton of all planting dates, as indicated by Fig. 1. The time interval between the 25 and the 50% stage was very short and shows that heavy dying of plants occurred during late August and early September. Fig. 1 shows a tendency for the 25, 50, and 75% stages of infection to be reached earlier in the early than in the late plantings. This would indicate a more rapid development of the disease in the early cotton. Data in Table 2 show this tendency more forcibly. August 11 has previously been cited as a critical date from which

judgment of root-rot losses may be made. From Table 2 it may be seen that the losses sustained to stands of cotton by August 11 were greater the earlier the cotton was planted. By correlating the age of cotton as of August 11 with the percentage of root-rot for each plat

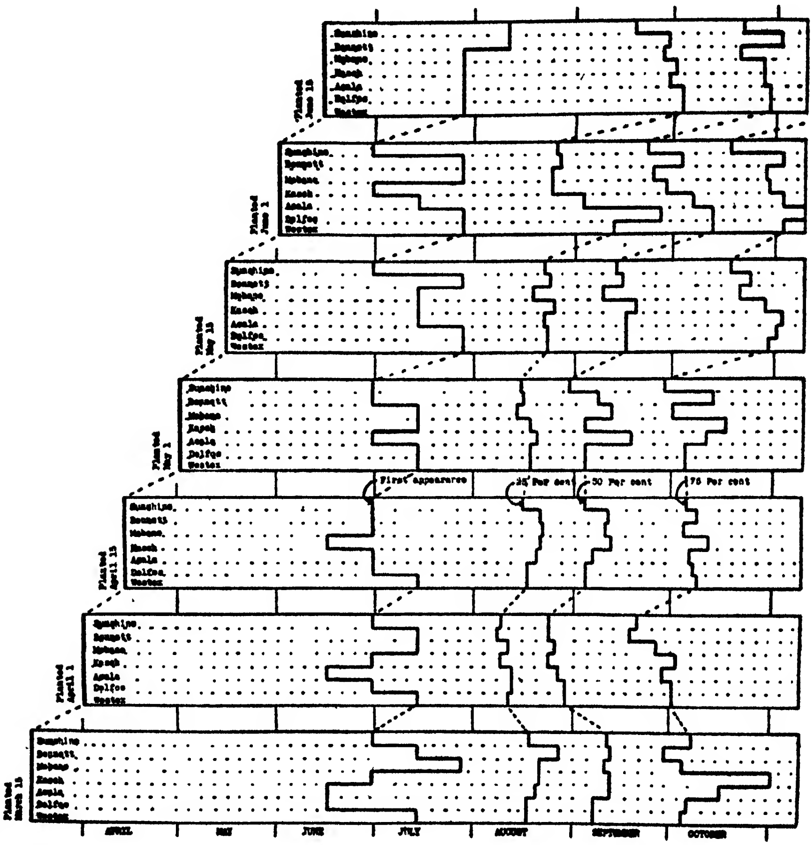

FIG. 1.—Graph developed from data secured at Temple, Texas, in 1928. From left to right, the main vertical lines indicate the date of planting, date of first appearance of root-rot, and dates at which 25, 50, and 75% of plants in the test were diseased, respectively.

at the same date, a positive coefficient of $.719 \pm .046$ was secured. This would indicate that the older the cotton the higher the percentage of root-rot.

The loss to stand in the Delfos variety by August 11 was 16.1, 23.5, 17.6, 11.0, 8.0, 3.6, and 1.4%, respectively, for the planting dates from March 15 to June 15, inclusive. While the March 15 record particularly does not fall in line, any grouping of these data on the basis of

TABLE 2.—*Percentage of total plant population dead from root-rot on August 11 and at end of season, November 3, for seven varieties of cotton planted at seven dates at Temple, Texas, 1928.*

	Planting dates						
	March 15	April 1	April 15	May 1	May 15	June 1	June 15
			Westex				
Dead Aug. 11, %	11.6	25.3	14.1	13.3	8.2	11.7	2.2
Dead Nov. 3, %	82.0	86.5	86.2	80.1	75.8	76.1	52.2
Total population	277.0	296.0	319.0	316.0	306.0	309.0	270.0
			Delfos				
Dead Aug. 11, %	16.1	23.5	17.6	11.0	8.0	3.6	1.4
Dead Nov. 3, %	85.0	87.2	85.3	89.8	76.0	62.7	52.2
Total population	274.0	297.0	319.0	264.0	325.0	308.0	297.0
			Acala				
Dead Aug. 11, %	13.9	22.0	13.4	13.7	9.7	7.5	2.1
Dead Nov. 3, %	81.9	87.5	83.1	87.7	74.8	74.1	52.9
Total population	310.0	296.0	314.0	300.0	310.0	294.0	293.0
			Kasch				
Dead Aug. 11, %	13.6	27.9	14.1	12.7	8.5	10.4	0.7
Dead Nov. 3, %	75.5	86.7	86.9	84.0	77.7	76.6	54.6
Total population	221.0	233.0	305.0	300.0	260.0	299.0	271.0
			Mebane				
Dead Aug. 11, %	13.6	24.6	10.7	19.9	10.4	8.0	2.2
Dead Nov. 3, %	84.5	88.8	87.2	87.0	79.1	77.5	58.7
Total population	103.0	187.0	381.0	241.0	249.0	289.0	269.0
			Bennett				
Dead Aug. 11, %	5.7	29.8	13.0	18.1	9.4	8.1	0.7
Dead Nov. 3, %	97.5	89.3	86.3	83.9	80.2	75.1	51.1
Total population	245.0	252.0	291.0	304.0	318.0	297.0	272.0
			Sunshine				
Dead Aug. 11, %	17.4	27.8	17.2	16.8	11.6	11.5	2.2
Dead Nov. 3, %	85.5	88.9	86.8	88.3	80.9	82.8	55.2
Total population	587.0	557.0	605.0	583.0	612.0	575.0	583.0

early and late planting dates will give averages indicating a much higher incidence of root-rot in the earlier plantings. The figures in Table 2 also give the percentage of plants dead at the end of the season. It will be noted that more than 80% of the early and midseason plantings died from root-rot, while more than 50% died in the June 15 planting.

It may be seen, then, that the time of planting cotton in 1928 had only a very limited influence on the initial appearance of the disease from plat to plat. Such records as indicate a relationship of initial infection to planting date were obtained from the late plantings after the major environmental factors were favorable. The date of planting did affect the subsequent development of root-rot, however. By

August 11, prior to the maturing of any bolls, the earlier planted cotton had sustained the greatest losses in stand.

RESULTS SECURED IN 1929

In 1929, the time intervening between the planting dates and first infections was progressively shorter for plantings made April 22, May 4, and May 20, respectively, as shown by Fig. 2. This condition was produced by the failure of the date of first appearance to ad-

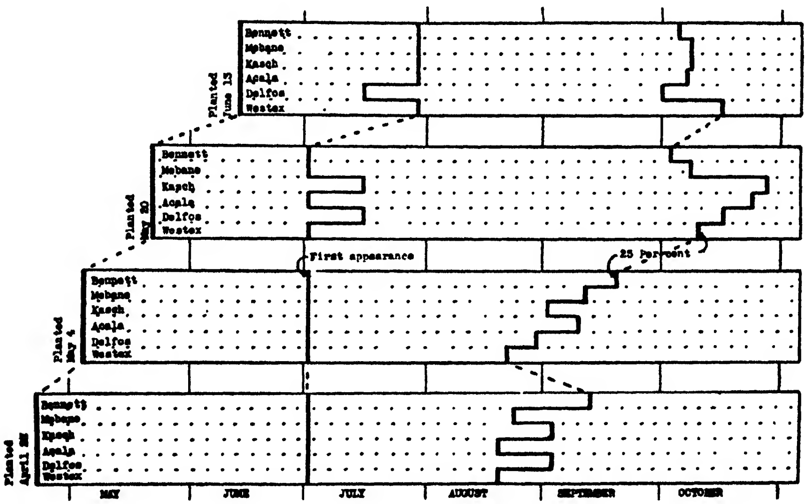

FIG. 2.—Data secured from plantings of six varieties on four dates in 1929. The main vertical lines indicate planting date, the date of first appearance of root-rot, and the date at which the disease had involved 25% of the plants in each variety group, respectively.

vance with the delay in planting, as was explained for a similar situation in 1928. These three dates of planting show little or no relation of age of plant to the initial appearance of the disease. However, the delayed planting of June 13 seemed to have delayed the initial root-rot infection approximately 30 days. The early disease-free period for the June 13 planting was nearly as long as for the May 20 planting.

The seasonal conditions in 1929 were not as favorable for a rapid development of root-rot as in 1928. Only one area, that planted to Westex on April 22, developed more than 50% of root-rot for the season. All plantings died in excess of 25%, however. This stage of infection was reached earlier by the April 22 than by the June 13 plantings. The general tendency, as brought out in Fig. 2, was for the earlier plantings to reach the 25% infection point earlier than the later plantings. This tendency is also demonstrated in Table 3.

The percentages of infection as of August 12 for the Delfos variety, are cited as typical. By August 12, the plantings of April 22, May 4, May 20, and June 13 showed losses of 21.3, 17.0, 7.1, and 6.4%, respectively. The rapid development of root-rot early in the season was evidently favored by moist soil conditions in May and June. Likewise, the late season development was slow and the final losses for the season were low due to unfavorable dry weather during July and August.

TABLE 3.—*Percentage of total plant population dead from root-rot on August 12 and at end of season, November 4, for six varieties of cotton planted on four dates, at Temple, Texas, 1929.*

	Planting dates			
	April 22	May 4	May 20	June 13
Westex				
Dead Aug. 12, %	20.5	21.3	9.8	5.4
Dead Nov. 4, %	51.7	43.9	30.2	29.0
Total population	1,511.0	1,500.0	329.0	1,034.0
Delfos				
Dead Aug. 12, %	21.3	17.0	7.1	6.4
Dead Nov. 4, %	46.1	41.5	30.2	34.6
Total population	1,528.0	1,552.0	354.0	1,090.0
Acala				
Dead Aug. 12, %	16.5	15.1	8.3	3.8
Dead Nov. 4, %	42.9	42.9	25.5	36.2
Total population	1,557.0	1,557.0	387.0	949.0
Kasch				
Dead Aug. 12, %	16.5	13.6	14.4	3.7
Dead Nov. 4, %	46.3	43.4	32.9	40.6
Total population	1,497.0	1,292.0	292.0	891.0
Mebane				
Dead Aug. 12, %	19.7	18.7	9.1	6.2
Dead Nov. 4, %	45.8	45.6	27.1	41.6
Total population	1,486.0	1,464.0	289.0	565.0
Bennett				
Dead Aug. 12, %	18.8	15.0	11.5	4.0
Dead Nov. 4, %	48.8	44.1	33.4	41.5
Total population	1,450.0	1,455.0	303.0	991.0

In 1929, the date of planting cotton influenced the development of root-rot in very much the same way as in 1928. The disease appeared uniformly throughout most of the plantings at about the same time independently of the age of the crop. Extremely late plantings showed a limited tendency for initial infection to await the development of the cotton plant. After the disease appeared the most rapid development was in the older cotton and resulted in great losses prior to boll forming time.

RESULTS SECURED IN 1930

The early disease-free period in the 1930 season was longest for the early planted cotton and progressively shorter for the later plantings. The delayed planting was associated with a slight delay in appearance of the disease, but was by no means equivalent to the delay in planting. Thus, making comparisons from Fig. 3, the May 1 planting was 20 days later than the April 10 seeding, but was accompanied with less than a 10-day delay in appearance of the disease. Again a 28-day delay in planting on May 29 as compared with May 1 produced

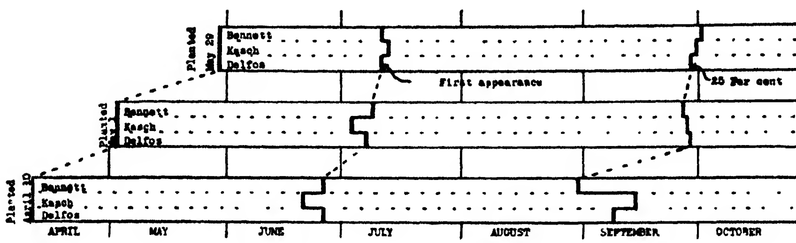

FIG. 3—Data secured in 1930 from plantings of three varieties on three dates. The main vertical lines indicate the planting date, the date of first appearance of root-rot, and the date at which 25% of the plants were diseased in each variety group, respectively.

only a negligible delay in the appearance of root-rot. The influence of the date of planting on the first appearance was greater in 1930 than in any other year covered by these tests; yet, factors other than age of the cotton plant appear to account in a large measure for the time at which root-rot makes its first appearance in the spring.

During 1930, the April 10 planting of Bennett developed more than 50% root-rot for the season. The figures for other varieties and other planting dates ranged from 31.0 to 47.5%, as shown in Table 4. All plantings reached the 25% infection stage, as shown in Fig. 3. The date at which 25% of the crop in the earliest planting, April 10, was dead was reached earlier than for other plantings. This tendency of root-rot to develop faster in earlier plantings is illustrated by the figures for Delfos in Table 4. By August 11 root-rot had killed 23.8, 13.6, and 7.0% of the crop for the April 10, May 1, and May 29 plantings, respectively.

It is seen that the same general trend appearing in the two previous years was again manifested in 1930. The initial appearance of the disease was determined largely by environmental factors and the greatest losses prior to August 11 were in the earliest planting.

TABLE 4.—*Percentage of total plant population dead from root-rot on August 11 and at end of season, October 20, for three varieties of cotton planted on three dates at Temple, Texas, 1930.*

	Planting dates		
	April 10	May 1	May 29
Delfos			
Dead Aug. 11, %	23.8	13.6	7.0
Dead Oct. 20, %	44.6	41.8	31.0
Total population	1,582.0	1,578.0	1,759.0
Kasch			
Dead Aug. 11, %	21.2	12.4	6.1
Dead Oct. 20, %	47.5	41.5	34.4
Total population	1,211.0	1,436.0	1,674.0
Bennett			
Dead Aug. 11, %	22.6	11.1	7.4
Dead Oct. 20, %	52.1	39.0	40.0
Total population	1,264.0	1,508.0	1,577.0

DISCUSSION

From the results secured in 1928, 1929, and 1930 from experiments with various planting dates, it was found that root-rot developed differently in plats of cotton of varying age. The severity of the losses from year to year differed considerably. The extent to which date of planting and therefore age of crop influenced the disease varied also, but throughout the period this factor operated in the same direction and was of relatively the same importance.

The age of the crop influenced the first appearance of the disease. In no instance was the time interval between the planting and first occurrence of the disease less than 30 days. That the age of cotton within certain limits delayed the appearance of the disease was clearly demonstrated in each year of the test. Very young cotton, regardless of when it was planted, was seldom killed by root-rot. For the planting of June 15, 1928, the initial root-rot infections were later on the average than in the planting made June 1. Planting as late as June 1 delayed the appearance of the disease when compared with planting May 15. In 1929, the appearance of the disease was later for the planting of May 20 than for the planting on May 4, and still later for the planting made June 13. Again, in 1930, plantings made May 1 and May 20 showed a greater delay in the appearance of the disease in comparison with the planting of April 10. In all of the extremely late plantings it appears that the initial infection of root-rot was delayed unil the plant reached a certain age and development.

This relationship of age of cotton to initial root-rot infection was totally absent in the earlier planting. For these plantings some other factor or factors were of greater importance. Environmental factors are known to exert a determining influence on the disease. Taubenhaus and Dana[6] in a study of moisture and temperature found that, at the first of the season, temperature had a distinct influence on the progress of the disease. Lack of moisture was also a limiting factor in the development of root-rot, but during the spring months the moisture is usually abundant. Temperature is one prominent environmental factor changing rapidly as the season advances. The uniformity with which the disease appears in these early plantings would suggest that temperature had a deciding influence. Regardless of what environmental factor or factors were responsible, it was apparent that the age of the host was a very minor factor early in the season in determining the initial appearance of the disease.

After root-rot was established and temperatures had become favorable for the disease, the age of the plant had a pronounced influence. This was especially true under favorable moisture conditions. The work of Taubenhaus and Dana has shown that during this period moisture may be, and often is, the most important factor. Nevertheless, it was demonstrated in every year of the present study that root-rot developed fastest in the older cotton. The records of infection as of August 11, particularly, bear out this fact. The records of Delfos may be mentioned to cover this point. In 1928, the losses were 16.1, 23.5, 17.6, 11.0, 8.0, 3.6, and 1.4% in early to late plantings from March 15 to June 15. In 1929, the percentages were 21.3, 17.0, 7.1, and 6.4 and from April 22 to June 13 in the order named. And again, in 1930, plantings made April 10 to May 20 showed a rapid decline in percentages in the order of 23.8, 13.6, and 7.0.

SUMMARY

Six varieties of cotton representing early, medium, and late varieties were planted in 1928 on seven dates and in 1929 on four different dates. In 1930, three of these varieties were planted on three different dates.

The Houston soils on which the plats were placed are very favorable to the root-rot as shown by the amount of disease found in crops preceding 1928 and the abundance of disease in the plats during the 3 years of this study.

That the cotton plant must attain a certain age under field conditions before it is subject to the disease was indicated by the delay in

[6]*Loc. cit.*

appearance of root-rot in cotton planted late as compared to early and midseason plantings.

Root-rot appeared at nearly the same time in the early and midseason plantings for the 1928 season. The same general trend was evident in the results secured in 1929 and 1930. This indicates that there was a strong factor influencing the time of first appearance of the disease and that this factor was not the age of the host plant. Previous studies indicate that temperature has a very strong influence on the early season activity of the disease.

Early planted cotton had a longer period of development before being attacked by root-rot, but the development of the disease was more rapid in the early than in the late plantings. The greatest losses were sustained by the early plantings.

COLORIMETRIC METHODS FOR THE DETERMINATION OF READILY AVAILABLE PHOSPHORUS IN SOILS[1]

C. O. Rost and R. M. Pinckney[2]

A number of rapid methods, based on the colorimetric method of Dénigès (2)[3], have been proposed for the determination of readily available phosphorus in soils. They depend upon the formation of the blue color developed by the action of a reducing agent on phosphomolybdic acid and are designed to indicate whether or not the use of phosphate fertilizer is likely to prove beneficial. The usual procedure is to treat a small amount of soil with a dilute acid, add ammonium molybdate, and then reduce the phosphomolybdic acid with stannous chloride or by stirring the acid extract with a tin rod. Where the mixture is not filtered an acid solution of ammonium molydate is used. The blue coloration developed is compared with that produced in a standard phosphate solution or with a standard color chart.

Very few studies have appeared showing the reliability of these tests when gauged by field responses to phosphate fertilizers. Bray (1), who developed the Illinois adaptation of the test, found a satisfactory agreement between the results of the test and the field response on 29 out of 31 experimental fields in Illinois. In general, the fields which gave a "high" or "medium" blue coloration did not show a profitable response from the use of rock phosphate, while those show-

[1]Contribution from the Division of Soils, Minnesota Agricultural Experiment Station, St. Paul, Minn. Journal Series Paper No. 1047. Received for publication September 19, 1931.

[2]Associate Professor and Instructor in Soils, respectively.

[3]Reference by number is to "Literautre Cited," p. 395.

ing no coloration or only slight coloration gave profitable returns. Spurway (3), using a water extract, tested soil from 47 locations and found that the application of phosphate fertilizers increased crop yields on all soils that showed a water-soluble content of phosphorus of less than 0.5 p.p.m.

The two methods developed by Truog (4) and the one by Bray (1) were used in testing the soil of the control plats of 10 experimental fields in Minnesota. On all of these fields the response to phosphate fertilizers was already known.

METHODS USED

The methods used included the Illinois test as developed by Bray, the Wisconsin method of Truog, and the La Motte-Truog commercial outfit. In the first a small test tube or vial is filled one-fourth full of soil and the tube filled three-fourths full of a hydrochloric acid solution of ammonium molybdate and shaken until the soil and solution are mixed. After about 5 minutes, by which time the soil has settled, the supernatant clear solution is stirred gently with a tin rod until the maximum intensity of color develops. The color is then compared with a standard color chart and classified as low, doubtful, medium, or high. When the amount of available phosphorus is low, the solution is colorless; when doubtful, a light green color develops after stirring; when medium and high, the color is blue and the difference is one of intensity.

With the La Motte-Truog soil phosphorus test about a half gram of soil is placed in a vial, 7 cc of water and 3 drops of a prepared sulfuric acid added, the mixture shaken vigorously for exactly 1 minute, and filtered into another vial having a mark one-half inch from the bottom. When the filtrate reaches the mark the tube is removed, 3 drops of an ammonium molydate solution added, and the contents shaken. The reducing agent is then added, the mixture shaken, and after 1 minute is compared with the color chart. According to the directions accompanying the outfit, the fine-textured soils of the northern states should carry 75 pounds of available phosphorus per acre and sands 50 pounds for successful crop production.

In the Wisconsin method 2 grams of soil and 400 cc of 0.002 N sulfuric acid, which has been buffered with ammonium sulfate to a pH of 3, are placed in a suitable container, shaken for 30 minutes, and filtered. The filtrate is not collected until it begins to come through perfectly clear. Two cc of ammonium molybdate-sulfuric acid solution and 3 drops of stannous chloride are added to 50 cc of the filtrate and the color compared in Nessler tubes with that of a standard

phosphate solution treated in the same way. When determined by this method Truog tentatively set the minimun limit of readily available phosphorus for general farming under Wisconsin conditions at 75 pounds per acre in the plowed layer for the finer textured soils and at 50 pounds for the very sandy soils.

FIELDS TESTED

The 10 fields tested included two of Carrington loam, the Nelson and Jorstad fields; three of Marshall silt loam, the Voxland, Sands, and Swanson fields; four of Fargo silt loam, Galley A, Galley B, Danielson, and Ronning fields; and one of Carrington silty clay loam, the Dokken field. About half of the plats on each field have been under experiment for 2 seasons, with corn the first year and small grain the second, while the others were under trial in 1930 only, using corn and barley as the trial crops.

In the 2-year experiment, which will be referred to as Experiment I, there were 24 plats of 1/25 acre size on each field. The plats were laid out three series in width and eight in length. The six control plats were in the center series so that each plat receiving phosphate fertilizer was adjacent to a control plat. In 1929 all fields were planted to corn and the plats receiving 100 pounds per acre of 40% superphosphate in the hill were used to measure the response to phosphate. In 1930 the test crop was barley and the response to phosphate was measured by the yield on plats which had received 100 pounds per acre of 40% superphosphate, half applied in the hill and half broadcast for corn in the previous season.

For the 1-year experiment, referred to as Experiment II, there were 48 plats 1/50 acre in size, laid out in three series of 16 plats each. On the center series eight of the plats were controls. Corn was used on six fields and barley on two; the ninth field, Ronning, being used for a different experiment in this season. The comparison made in Experiment II was between the controls and the plats receiving 100 pounds per acre of 40% superphosphate applied in the hill for corn and a like amount spread broadcast for barley. In the case of the latter the fertilizer was spread previous to seeding and disced in.

On each control plat five sets of soil samples were collected, one near each corner and one in the center. Each set consisted of three samples, one from the surface, one from the 12-inch depth, and a third from a 20-inch depth. The surface sample represented the surface 2 inches of soil, while the 12-inch sample was made up of soil from 11 to 13 inches deep and the 20-inch sample of soil from 19 to 21 inches. Each sample was tested separately by the Illinois test in-

order to obtain information as to the distribution of readily available phosphate on an area as small as 1/25 or 1/50 acre. To indicate the supply in the soil of the plat as a whole, the tests of the five individual samples from each depth were averaged. In order to do this, "low" was ranked as 1, "doubtful" as 2, "medium" as 3, and "high" as 4. In the case of the La Motte-Truog test and the Wisconsin method determinations were made on composite samples made by combining equal amounts of soil from each depth from the five locations on the plat.

VARIATION IN AMOUNTS OF READILY AVAILABLE PHOSPHORUS ON SMALL PLATS AND FIELDS

The amounts of readily available phosphorus found in the soil from different parts of the small plats used in this study were fairly uniform for each depth, but in a few cases showed wide variations. The results of the Illinois test on samples from five locations and from three depths on four control plats on each of the nine fields used in Experiment I are given in Table 1. The plats were 75 feet long and 28 feet wide and samples were taken on diagonal lines from opposite corners,

TABLE 1.—*Available phosphorus by Illinois test in soil samples from five locations on 36 plats from nine experimental fields.**

Plat No.	Location on plat	Depth of sample			Depth of sample			Depth of sample		
		Surface	12 ins.	20 ins.	Surface	12 ins.	20 ins.	Surface	12 ins.	20 ins.
		Nelson Field			Jorstad Field			Dokken Field		
B 1	NW	1	1	4	3	4	4	1	1	4
	SW	1	4	4	3	4	4	1	1	2
	SE	1	1	4	3	4	4	3	4	4
	NE	1	1	2	3	4	4	4	4	4
	Center	1	1	1	1	4	4	1	4	4
B 3	NW	1	1	1	2	3	4	3	4	4
	SW	1	1	1	2	4	4	3	4	4
	SE	1	1	1	2	4	4	3	4	4
	NE	1	1	2	2	4	4	3	4	4
	Center	1	1	2	2	3	4	4	4	4
B 5	NW	1	1	1	1	4	4	1	1	1
	SW	1	1	1	1	2	4	1	1	1
	SE	1	1	1	1	1	4	1	1	3
	NE	1	1	3	1	2	4	1	1	3
	Center	1	1	1	1	1	4	1	1	1
B 7	NW	1	1	1	1	3	4	2	3	4
	SW	1	1	3	2	3	3	1	2	4
	SE	1	1	1	1	3	4	3	4	4
	NE	1	2	4	1	2	4	1	3	4
	Center	1	2	4	1	1	4	3	4	4

*1 = low; 2 = doubtful; 3 = medium; and 4 = high.

TABLE 1.—*Concluded.*

Plat No.	Location on plat	Depth of sample			Depth of sample			Depth of sample		
		Surface	12 ins.	20 ins.	Surface	12 ins.	20 ins.	Surface	12 ins.	20 ins.
		Voxland Field			Sands Field			Swanson Field		
B 1	NW	1	1	3	1	1	4	1	1	3
	SW	1	1	4	1	1	3	1	1	4
	SE	1	1	4	1	1	3	3	1	3
	NE	1	1	3	1	1	4	1	2	4
	Center	1	1	2	1	1	3	1	1	4
B 3	NW	1	1	4	1	1	4	1	1	4
	SW	1	3	4	1	1	4	1	3	4
	SE	1	1	3	1	1	4	1	3	4
	NE	1	1	4	1	1	4	1	3	4
	Center	1	1	4	1	1	4	1	3	4
B 5	NW	1	3	4	1	1	4	1	3	4
	SW	1	3	4	1	1	4	1	1	2
	SE	1	1	4	1	1	4	1	4	4
	NE	1	1	4	1	1	4	1	1	4
	Center	1	1	3	1	1	3	1	2	4
B 7	NW	1	1	3	1	1	4	1	1	4
	SW	1	1	3	1	2	4	3	2	4
	SE	1	1	4	1	1	3	4	2	4
	NE	1	1	3	1	1	4	4	4	4
	Center	1	1	4	2	3	4	4	3	4
		Galley Field			Danielson Field			Ronning Field		
B 1	NW	1	4	4	1	1	2	1	2	1
	SW	1	2	4	1	2	4	1	1	2
	SE	1	2	4	1	1	3	1	3	1
	NE	1	2	4	1	1	3	1	1	2
	Center	1	3	4	1	1	3	1	1	1
B 3	NW	1	1	1	2	2	4	1	1	1
	SW	1	3	4	1	1	3	2	1	2
	SE	1	1	2	2	2	2	1	1	1
	NE	1	1	3	1	2	4	1	1	2
	Center	1	1	2	2	1	4	1	2	3
B 5	NW	1	2	4	2	3	4	1	1	2
	SW	1	1	1	1	3	4	1	1	1
	SE	1	1	3	2	2	4	1	1	1
	NE	1	3	4	1	4	4	1	1	1
	Center	1	1	4	3	2	4	1	1	1
B 7	NW	1	2	4	1	1	3	2	3	4
	SW	2	3	4	1	1	2	2	1	3
	SE	1	3	4	1	1	2	1	1	3
	NE	1	3	4	1	1	3	2	3	4
	Center	1	2	4	1	1	4	2	4	4

10 feet from each corner and at the intersection in the center. The places of sampling at the ends of the plat were 14 feet apart and these were approximately 30 feet from the center location. The longest distance was 60 feet between locations on the two ends of the plat.

The extreme variation which may occur on a plat of this size is shown by plat B1 of the Dokken field (Table 1). The surface at the west end was low in available phosphate, but 60 feet away on the east end it was medium and high. In the center the surface tested low, but the 12- and 20-inch depths were high like those at the east end of the plat. An example of uniformity in the distribution of available phosphate is to be found on plat B3 of the same field located approximately 80 feet east of B1. Here the surface soil tests medium in all cases but one, and all samples from the 12- and 20- inch depths test high.

The Dokken and Jorstad fields serve as examples which show rather wide variations in different parts of the same field. The Voxland and Sands fields show, on the other hand, that there may be very uniform plats and fields. The remaining five fields are intermediate, showing some, although not extreme, variation in the amounts of available phosphorus present in different parts of the field.

AGREEMENT OF METHODS

The results of tests by the three methods are shown in Tables 2 and 3. There was in general a close agreement between amounts of available phosphate as shown by the LaMotte-Truog test and the Wisconsin method. In most cases the amounts shown by the latter were slightly lower than those shown by the former. The averages for the three depths for the different fields did not vary more than 6 pounds per acre except in two cases. On the Danielson field the LaMotte-Truog test showed 9 pounds less and on Galley B field 8 pounds more than the Wisconsin method.

There is a general concordance between the results secured with the Illinois test and those secured by the other two methods. No attempt has been made to assign any number of pounds of readily available phosphorus to the low, doubtful, medium, and high categories because of the wide variations when gauged by the other methods.

AMOUNTS OF AVAILABLE PHOSPHORUS PRESENT

The amount of readily available phosphorus in the surface soil of all fields, except Galley B, was low (Tables 2 and 3). When measured by the Wisconsin method it varied in Experiment I from an average of 8 pounds for the Nelson field to 25 pounds for the Swanson field. On the land used in Experiment II the amounts were no greater except on the Galley B field which carried 87 pounds of available phosphorus. The field used in Experiment II was a half mile distant from that used in Experiment I.

TABLE 2.—*Available phosphorus by the Illinois, La-Motte-Truog and Wisconsin methods in soils from nine experimental fields started in 1929, Experiment I.*

Plat No.	Illinois test*				La Motte-Truog test				Wisconsin method				Relative yield with 0-40-0	
	Surface	12 inches	20 inches	Average	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Surface, lbs.	12 inches, lbs.	20 inches, lbs	Average, lbs.	Corn, 1929	Barley, 1930
							Nelson Field							
B 1	1.0	1.6	3.1	1.9	10	10	25	15	10	10	26	15	222	124
B 7	1.0	1.5	2.7	1.7	10	10	15	12	9	7	17	11	197	89
B 6	1.0	1.6	1.0	1.2	10	10	10	10	3	9	6	6	212	93
B 3	1.0	1.0	1.5	1.2	10	10	15	12	9	6	11	9	166	126
B 5	1.0	1.0	1.5	1.2	15	10	15	13	8	5	13	9	154	96
B 2	1.0	1.0	1.4	1.1	15	10	10	12	11	4	10	8	169	102
Av.	1.0	1.2	1.9	1.4	12	10	15	12	8	7	14	10	187	105
							Jorstad Field							
B 2	3.5	4.0	3.9	3.8	30	60	125	72	25	51	126	67	105	121
B 1	2.5	4.0	4.0	3.5	30	75	200	102	24	66	180	90	99	95
B 3	2.6	3.6	4.0	3.4	25	50	200	92	16	39	200	85	106	109
B 7	1.2	2.5	3.9	2.5	15	20	75	37	9	15	60	28	97	109
B 5	1.1	2.1	4.0	2.4	15	25	100	47	11	25	90	42	107	113
B 6	1.0	2.1	3.8	2.3	20	10	30	20	17	13	23	18	100	103
Av.	2.0	3.1	3.9	3.0	22	40	122	61	17	35	113	55	102	108
							Voxland Field							
B 5	1.1	1.7	3.9	2.2	15	15	15	15	16	13	12	14	113	157
B 6	1.0	1.6	3.4	2.0	20	20	40	27	34	35	36	35	118	124
B 3	1.0	1.3	3.8	2.0	10	15	20	15	12	11	23	15	115	103
B 7	1.0	1.0	3.3	1.8	10	10	45	22	9	10	37	19	115	136
B 1	1.0	1.0	3.1	1.7	15	15	30	20	10	12	28	17	104	86
B 2	1.1	1.2	2.5	1.6	25	20	30	25	23	19	24	22	99	82
Av.	1.0	1.3	3.3	1.9	16	16	30	21	17	17	27	20	111	115

*1 = low; 2 = doubtful; 3 = medium; 4 = high.

TABLE 2.—*Concluded.*

Plat No.	Illinois test*				La Motte-Truog test				Wisconsin method				Relative yield with 0-40-0	
	Surface	12 inches	20 inches	Average	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Corn, 1929	Barley, 1930
							Sands Field							
B 2	1.9	2.6	3.4	2.6	20	15	20	18	17	13	16	15	115	—
B 7	1.5	1.7	3.8	2.3	25	25	30	27	15	20	31	22	105	—
B 6	1.4	1.6	3.8	2.3	25	10	20	18	25	5	13	14	120	—
B 3	1.1	1.0	4.0	2.0	15	15	60	30	11	12	52	25	109	—
B 5	1.0	1.0	3.8	1.9	20	20	50	30	14	15	54	28	121	—
B 1	1.1	1.0	3.3	1.8	20	15	10	15	15	14	13	14	139	—
Av.	1.3	1.5	3.7	2.2	21	17	32	23	16	13	30	20	118	—
							Swanson Field							
B 7	3.2	2.6	4.0	3.3	80	45	50	58	64	56	47	56	91	92
B 3	1.0	2.5	4.0	2.5	20	25	75	40	17	21	67	35	97	85
B 6	1.2	2.3	3.6	2.4	10	10	30	17	7	10	32	16	89	105
B 5	1.0	2.2	3.6	2.3	25	20	35	27	36	20	43	33	85	107
B 1	1.5	1.2	3.7	2.1	20	25	65	37	16	24	55	32	108	83
B 2	1.0	2.2	2.9	2.0	10	10	20	13	8	10	14	11	111	83
Av.	1.5	2.2	3.6	2.4	27	23	46	32	25	23	43	30	97	93
							Dokken Field							
B 3	3.3	4.0	4.0	3.8	25	75	55	52	40	60	46	49	111	132
E 3	2.1	2.9	4.0	3.0	20	50	150	73	19	45	142	69	89	116
B 1	2.1	2.8	3.6	2.8	20	60	80	53	18	56	84	53	161	106
E 1	1.1	1.0	2.1	1.4	15	15	150	60	11	12	144	56	102	100
Av.	2.2	2.7	3.4	2.8	20	50	109	60	22	43	104	57	116	113

Galley A Field														
B7	1.3	2.6	4.0	2.6	30	50	125	68	22	44	112	59	297	122
B6	1.6	2.4	4.0	2.7	15	40	95	50	11	33	86	43	187	112
B1	1.2	2.7	4.0	2.6	30	60	175	88	28	55	162	82	123	84
B5	1.0	1.6	3.1	1.9	30	30	80	47	22	26	71	40	130	93
B2	1.0	1.2	2.9	1.7	20	15	25	20	12	10	22	15	128	92
B3	1.0	1.4	2.6	1.7	25	25	60	37	22	24	58	35	105	81
Av.	1.2	1.9	3.4	2.2	25	37	93	52	20	32	85	46	162	97
Danielson Field														
B5	2.0	3.0	4.0	3.0	50	65	180	98	43	58	144	82	118	181
B6	1.7	3.3	4.0	3.0	15	55	100	57	13	44	92	50	82	129
B3	1.6	1.9	3.3	2.3	45	50	175	90	31	42	162	78	82	118
B7	1.0	1.0	3.1	1.7	25	10	30	22	16	6	20	14	119	122
B1	1.0	1.2	2.7	1.6	18	25	45	29	19	16	40	25	94	107
B2	1.0	1.3	2.5	1.6	10	20	20	17	6	16	18	13	113	112
Av.	1.4	2.0	3.3	2.2	27	37	92	52	21	30	79	44	101	127
Ronning Field														
B2	1.9	3.1	4.0	3.0	25	25	35	28	24	20	29	24	103	86
B7	2.0	2.5	3.6	2.7	25	60	135	73	22	46	120	63	146	151
B3	1.3	1.0	2.0	1.4	20	25	40	28	16	21	32	23	99	109
B6	1.0	1.0	2.1	1.4	20	40	95	52	18	33	86	46	122	131
B1	1.0	1.6	1.4	1.3	35	20	20	25	30	14	17	20	115	95
B5	1.0	1.0	1.6	1.2	25	20	15	20	17	19	14	17	130	118
Av.	1.4	1.7	2.5	1.8	25	31	57	38	21	25	50	32	119	115

*1 = low; 2 = doubtful; 3 = medium; 4 = high.

TABLE 3.—*Available phosphorus by the Illinois, La Motte-Truog, and Wisconsin methods in soils from nine experimental fields started in 1930, Experiment II.*

Plat No.	Illinois test*				La Motte-Truog test				Wisconsin method				Relative yield with 0-40-0	
	Surface	12 inches	20 inches	Average	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Corn	Barley
							Nelson Field							
E 12	2.2	2.2	3.8	2.7	10	25	80	38	—	—	—	—	128	—
E 16	1.6	2.2	3.0	2.3	20	20	60	33	—	—	—	—	128	—
E 8	1.4	1.0	3.4	1.9	20	15	60	32	—	—	—	—	121	—
F 13	1.0	1.6	3.0	1.9	15	15	30	20	10	12	26	16	138	—
E 4	1.0	1.0	2.2	1.4	15	10	20	15	—	—	—	—	123	—
F 9	1.0	1.0	1.6	1.2	15	15	25	18	11	10	21	14	123	—
F 1	1.0	1.0	1.0	1.0	10	10	10	10	11	8	18	12	116	—
F 5	1.0	1.0	1.0	1.0	15	10	20	15	16	8	20	15	87	—
Av.	1.3	1.4	2.4	1.7	14	15	38	23	12	10	21	14	120	—
							Jorstad Field							
E 3	4.0	3.7	3.7	3.8	80	55	80	72	74	47	74	65	96	—
E 13	2.7	3.4	4.0	3.4	30	80	150	87	26	74	138	79	109	—
E 11	1.9	2.7	4.0	2.9	25	80	85	67	20	88	86	65	147	—
E 5	1.6	3.0	3.9	2.8	10	35	120	55	10	32	106	49	113	—
E 15	1.7	2.8	4.0	2.8	20	55	125	67	17	48	112	59	71	—
E 7	1.2	2.7	4.0	2.6	10	30	75	38	9	33	70	37	122	—
E 1	1.2	1.8	3.9	2.3	15	20	100	45	12	16	86	38	114	—
E 9	1.3	2.3	3.3	2.3	15	25	100	47	14	20	95	43	109	—
Av.	2.0	2.8	3.9	2.9	26	47	104	60	23	45	96	54	110	—
							Voxland Field							
E 7	1.8	2.2	4.0	2.7	35	25	90	50	29	20	84	44	98	—
E 5	1.6	1.4	4.0	2.3	35	15	65	38	26	12	60	33	108	—
E 9	1.6	1.3	4.0	2.3	30	15	80	42	27	14	67	36	94	—
E 13	1.0	1.4	3.6	2.0	25	15	85	42	19	12	76	36	117	—
E 1	1.0	1.0	3.2	1.7	35	10	70	38	26	11	61	33	117	—
E 3	1.0	1.0	3.2	1.7	30	15	25	23	24	14	25	21	106	—
E 15	1.0	1.0	2.6	1.5	15	10	85	37	13	7	75	32	103	—
E 11	1.0	1.0	2.4	1.5	20	10	60	30	17	9	53	26	107	—
Av.	1.3	1.3	3.4	2.0	28	14	70	37	23	12	63	33	106	—

Sands Field														
F 15	1.3	2.4	4.0	2.6	15	35	80	43	12	32	74	39	109	—
F 7	1.0	1.0	3.0	1.7	20	15	30	22	20	17	27	21	97	—
D 1	1.2	1.1	1.9	1.4	25	15	20	20	15	11	18	15	81	—
F 3	1.0	1.0	2.8	1.6	15	20	20	18	16	15	26	19	79	—
F 11	1.1	1.0	2.1	1.4	20	20	25	22	16	15	22	18	91	—
D 13	1.3	1.2	1.5	1.3	25	25	15	22	19	19	17	18	91	—
D 5	1.5	1.0	1.1	1.2	20	15	10	15	17	11	12	13	90	—
D 9	1.1	1.2	1.0	1.1	25	20	15	20	18	17	13	16	93	—
Av.	1.2	1.2	2.2	1.5	21	21	26	23	17	17	26	20	91	—
Swanson Field														
E 3	2.1	1.1	3.9	2.4	40	30	65	45	29	26	57	37	82	—
E 1	1.1	2.2	2.6	2.0	35	25	45	35	22	22	36	27	92	—
E 5	1.1	1.0	2.8	1.6	15	10	25	17	10	8	20	13	111	—
E 15	1.0	1.3	1.9	1.4	10	10	10	10	6	8	11	8	95	—
E 13	1.1	1.1	1.5	1.2	20	15	15	17	14	12	13	13	122	—
E 11	1.0	1.0	1.5	1.2	15	10	15	13	12	4	15	10	124	—
E 9	1.0	1.0	1.5	1.2	15	15	20	17	11	10	16	12	139	—
E 7	1.0	1.0	1.2	1.1	15	15	15	15	10	11	16	12	111	—
Av.	1.2	1.2	2.1	1.5	21	16	26	21	14	13	23	17	109	—
Dokken Field														
L 2	2.8	4.0	4.0	3.6	20	55	130	68	17	48	124	63	—	101
L 4	1.0	2.6	4.0	2.5	15	20	20	18	12	13	32	19	—	119
J 1	1.0	1.4	3.5	2.0	10	15	20	15	8	15	22	15	—	117
I 4	1.0	1.6	2.1	1.6	10	10	20	13	8	11	20	13	—	81
G 3	1.0	1.0	2.0	1.3	10	20	45	25	7	21	46	25	—	124
I 2	1.0	1.0	1.7	1.2	10	10	30	17	5	9	28	14	—	125
J 3	1.0	1.0	1.7	1.2	10	15	15	13	4	12	18	11	—	112
G 1	1.0	1.0	1.0	1.0	10	10	10	10	9	20	24	18	—	160
Av.	1.2	1.7	2.5	1.8	12	19	36	22	9	19	39	22	—	117
Galley B Field														
E 4	4.0	3.9	4.0	4.0	110	140	200	150	100	130	182	137	85	—
E 16	3.8	4.0	4.0	3.9	60	160	130	117	56	160	138	117	91	—
E 14	3.8	4.0	4.0	3.9	80	125	160	122	74	112	152	113	111	—
E 6	4.0	3.7	4.0	3.9	95	200	200	165	98	200	186	161	81	—
E 8	4.0	3.4	4.0	3.8	110	200	200	170	108	204	178	163	89	—
E 10	4.0	3.5	4.0	3.8	160	200	120	163	142	212	108	154	91	—
E 2	3.8	3.7	4.0	3.8	80	150	200	143	67	144	194	135	85	—
E 12	3.3	3.0	4.0	3.4	60	130	120	113	52	140	110	101	103	—
Av.	3.8	3.7	4.0	3.8	94	163	166	143	87	163	156	135	92	—

*1 = low; 2 = doubtful; 3 = medium; and 4 = high.

TABLE 3.—*Concluded.*

Plat No.	Illinois test*				La Motte-Truog test				Wisconsin method				Relative yield with 0-40-0	
	Surface	12 inches	20 inches	Average	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Surface, lbs.	12 inches, lbs.	20 inches, lbs.	Average, lbs.	Corn	Barley
							Danielson Field							
E 5	1.5	2.9	4.0	2.8	35	50	90	58	26	44	102	57	—	129
E 4	1.5	2.6	3.6	2.6	40	70	90	67	26	60	94	60	—	129
E 6	1.0	2.3	3.8	2.4	20	20	70	37	19	16	66	34	—	131
E 3	1.0	2.1	4.0	2.4	15	20	80	38	15	14	68	32	—	136
E 8	1.0	2.1	4.0	2.4	20	25	60	35	17	24	74	38	—	157
E 1	1.3	1.7	3.1	2.0	20	15	70	35	12	9	64	28	—	139
E 7	1.0	1.4	3.1	1.8	15	15	60	30	12	12	48	24	—	173
E 2	1.0	1.1	2.6	1.6	15	15	65	32	11	8	63	27	—	132
Av.	1.2	2.0	3.5	2.3	22	29	73	41	17	24	72	38	—	141

*1 = low; 2 = doubtful; 3 = medium; and 4 = high.

The amounts at the 12-inch level were slightly higher than at the surface in the case of Experiment I on the Jorstad, Dokken, and Galley fields, where they were 35, 43, and 32 pounds, respectively, of available phosphorus (Table 2). None of the fields in Experiment II carried any considerable amounts at the 12-inch depth, except Galley B which showed 163 pounds.

The amounts at the 20-inch level were low on five fields of Experiment I, *viz.*, the Nelson, Voxland, Sands, Swanson and Ronning fields. On these fields it varied from an average of 14 pounds for the Nelson field to 50 pounds on the Ronning field. Of the other four, the Jorstad field carried the largest amount, *viz.*, 113 pounds, and all contained more than 75 pounds. The fields of Experiment II carried similar amounts at this level, with the exception of the Dokken field where the amount present was much lower than on the tract used in Experiment I, and Galley B where the amount was higher.

RELIABILITY OF METHODS IN PREDICTING PHOSPHATE DEFICIENCY

ILLINOIS TEST

While the amount of soluble phosphorus found by the Illinois test generally varied in the same way as that found by the other two methods, no numerical value is assigned to the four categories. High and medium tests would indicate that the chances of increases in yield from phosphate were not promising while doubtful and low tests would be assumed to signify that phosphate would be beneficial.

In Table 4 the tests are arranged to show the responsiveness of the plats of the 10 fields, dividing those testing high, medium, doubtful, and low into separate groups. The averages of the tests of samples from the five locations (Tables 2 and 3) on each plat were used. An average of 1.0 to 1.5 was considered as being low, 1.6 to 2.5 as doubtful, 2.6 to 3.5 as medium, and 3.6 to 4.0 as high. The relative yield with phosphate was obtained by comparing the yield of the plat tested with that of one adjacent to it which had received 40% superphosphate at the rate of 100 pounds per acre. For corn the fertilizer was applied in the hill and for grain it was broadcast and disced in before seeding. The data are based on the yield of corn which was used exclusively in Experiment I and on corn and barley used in Experiment II. The comparison is made for the year that the phosphate was applied and does not include the responses of the second year of Experiment I.

Part I of Table 4 is based on the average of the tests of samples from the three depths, *viz.*, surface, 12 inches, and 20 inches, and

TABLE 4.—*Relation of Illinois test to field response to phosphate.*

Field	High		Medium		Doubtful		Low	
	Responsive	Nonresponsive	Responsive	Nonresponsive	Responsive	Nonresponsive	Responsive	Nonresponsive
				Average of Three Depths				
Nelson	0	0	1	0	5	0	7	1
Jorstad....	1	1	5	2	3	2	0	0
Voxland ...	0	0	0	1	8	3	1	1
Sands.. ...	0	0	2	0	5	2	0	5
Swanson...	0	0	0	1	3	5	4	1
Dokken....	1	1	1	1	2	1	4	1
Galley A ..	0	0	3	0	3	0	0	0
Galley B...	1	6	0	1	0	0	0	0
Danielson..	0	0	3	1	8	2	0	0
Ronning .	0	0	1	1	0	0	3	1
Total ..	3	8	16	8	37	15	19	10
Percentage	27	73	67	33	71	29	66	34
				Surface Samples Only				
Nelson	0	0	0	0	2	0	11	1
Jorstad....	0	1	3	0	2	2	4	2
Voxland.. .	0	0	0	0	1	2	8	3
Sands.. ..	0	0	0	0	1	0	6	7
Swanson...	0	0	0	1	0	1	7	5
Dokken ...	0	0	1	1	1	1	6	2
Galley A...	0	0	0	0	1	0	5	0
Galley B. .	1	6	0	1	0	0	0	0
Danielson	0	0	0	0	1	2	10	1
Ronning...	0	0	0	0	1	1	3	1
Total...	1	7	4	3	10	9	60	22
Percentage	13	87	58	42	53	47	73	27

represents the available phosphate in the upper 2 feet of soil. All plats with a relative yield of 105 or more were assumed to be responsive.

Eleven of the 116 plats tested high and of these 3, or 27%, responded to phosphate. Of the 24 testing medium, 16, or 67%, responded, this being practically the same as the percentage of those testing doubtful and low. For 52 doubtful plats, the percentage responding was 71, and for the 29 testing low 19, or 66%, responded.

Based on the average test of the upper 2 feet, a response from phosphate might be expected from about 70% of fields of this kind which tested low, doubtful, or medium. Of the fields testing high an occasional one might be expected to respond.

Comparing the responses to phosphate with the tests of the surface soil, somewhat similar indications are secured (Table 4, part 2).

There were 82 plats which tested low and of these 60, or 73%, responded to phosphate. A much smaller number of plats, 19, were doubtful. Ten responded to fertilizer and nine did not. Of the seven with a medium amount, four responded while only one of the eight with a high amount was responsive.

The reliability of the test when based on the examinations of surface samples only would not be materially changed. About 70% of those testing low might be expected to respond and half or more of those testing doubtful or medium would be responsive. Where high amounts are present there would be an occasional responsive field. The number of plats testing high and medium is too small to more than indicate that there are responsive fields carrying these amounts and that more from the medium group respond than from the high group.

LA MOTTE-TRUOG AND WISCONSIN METHODS

In these two methods the available phosphorus is expressed in pounds per acre. In the present study the amounts obtained with both were similar, usually the Wisconsin method giving a few pounds less per acre than indicated by the La Motte-Truog test. The determinations were made by the same operator in order to eliminate the personal factor so far as possible.

Truog (4) has suggested for Wisconsin conditions a tentative minimum limit of readily available phosphorus of 75 pounds per acre in the plowed layer of heavy soils and 50 pounds for sandy soils. All the soils used in this study would be classed as heavy so that if they behaved the same as Wisconsin soils a general response to phosphate might be expected where the surface layer carried less than 75 pounds per acre of readily available phosphorus. In judging the reliability of the methods the same conditions given above for the Illinois test were used.

The amounts found in the surface layers were very low (Tables 5 and 6). By the Wisconsin method, 87 out of 112 plats were found to carry less than 26 pounds per acre of readily available phosphorus and 108 less than 75 pounds. Six carried amounts varying between 51 and 75 pounds and four contained amounts greater than 75 pounds (Table 5, part 1). Of the 87 plats with amounts below 26 pounds 60, or 69%, responded to phosphate fertilizer, and of the 15 plats with 26 to 50 pounds of available phosphorus 11, or 73%, responded. Of the 10 plats with more than 50 pounds only 1 responded to phosphate.

From the data it would appear that under southeastern Minnesota conditions about 70% of the fields having less than 50 pounds of readily available phosphorus as determined by the Wisconsin method

TABLE 5.—*Relation of amounts of readily available phosphorus per acre as found by the Wisconsin method to field response to phosphate fertilizer.*

Field	76 lbs. or more		51 to 75 lbs.		26 to 50 lbs.		1 to 25 lbs.	
	Re-sponsive	Non-re-sponsive	Re-sponsive	Non-re-sponsive	Re-sponsive	Non-re-sponsive	Re-sponsive	Non-re-sponsive
				Surface Soil				
Nelson	0	0	0	0	0	0	9	1
Jorstad	0	0	0	1	1	0	8	4
Voxland	0	0	0	0	3	2	6	3
Sands	0	0	0	0	0	0	7	7
Swanson	0	0	0	1	1	1	7	4
Dokken	0	0	0	0	1	0	7	4
Galley A	0	0	0	0	1	0	5	0
Galley B	0	4	1	3	0	0	0	0
Danielson	0	0	0	0	3	1	8	2
Ronning	0	0	0	0	1	0	3	2
Total	0	4	1	5	11	4	60	27
Percentage	0	100	17	83	73	27	69	31
				Upper 2 Feet of Soil				
Nelson	0	0	0	0	0	0	9	1
Jorstad	2	1	2	2	5	1	0	1
Voxland	0	0	0	0	5	3	4	2
Sands	0	0	0	0	2	0	5	7
Swanson	0	0	0	1	1	4	6	2
Dokken	0	0	1	3	1	0	6	1
Galley A	1	0	1	0	3	0	1	0
Galley B	1	7	0	0	0	0	0	0
Danielson	1	1	2	0	6	1	2	1
Ronning	0	0	1	0	1	0	2	2
Total	5	9	7	6	24	9	35	17
Percentage	36	64	54	46	73	27	67	33

will respond to phosphate fertilizer and the remaining 30% will show no effect. The number of plats carrying more than 50 pounds in the surface is too small to more than indicate that most of the fields with amounts above 50 pounds will not respond to phosphate. A small percentage, however, may be expected to respond.

Predictions of phosphate deficiency based on an average of the amounts of readily available phosphorus found in samples taken at the surface, and at the 12-inch and 20-inch depths would be no more accurate than when based on the tests of surface samples only (Table 5, part 2). When the 2-foot layer carried 50 pounds or less about 70% of the fields might be expected to respond. Where 51 to 75 pounds were present, about half would respond and half would not, and where more than 75 pounds were present about one-third of the fields would respond.

Indications of phosphate deficiency obtained by the La Motte-Truog test are of much the same order as those obtained by the Wisconsin method (Table 6). For fields having 50 pounds or less of readily available phosphate in the surface layer 67 to 73% responded

TABLE 6.—*Relation of amounts of readily available phosphorus per acre as found by the LaMotte-Truog test to field response to phosphate fertilizer.*

Field	76 lbs. or more		51 to 75 lbs.		26 to 50 lbs.		1 to 25 lbs.	
	Re-spon-sive	Non-re-spon-sive	Re-spon-sive	Non-re-spon-sive	Re-spon-sive	Non-re-spon-sive	Re-spon-sive	Non-re-spon-sive
				Surface Soil				
Nelson	0	0	0	0	0	0	13	1
Jorstad	0	1	0	0	2	1	7	3
Voxland	0	0	0	0	3	2	6	3
Sands	0	0	0	0	0	0	7	7
Swanson	0	1	0	0	0	2	7	4
Dokken	0	0	0	0	0	0	8	4
Galley A	0	0	0	0	3	0	3	0
Galley B	1	5	0	2	0	0	0	0
Danielson	0	0	0	0	3	1	8	2
Ronning	0	0	0	0	1	0	3	2
Total	1	7	0	2	12	6	62	26
Percentage	12	88	0	100	67	33	71	29
				Upper 2 Feet of Soil				
Nelson	0	0	0	0	3	0	10	1
Jorstad	2	1	3	2	4	1	0	1
Voxland	0	0	0	0	5	3	4	2
Sands	0	0	0	0	4	0	3	7
Swanson	0	0	0	1	1	4	6	2
Dokken	0	0	2	3	0	0	6	1
Galley A	1	0	1	0	3	0	1	0
Galley B	1	7	0	0	0	0	0	0
Danielson	1	1	2	1	6	1	2	0
Ronning	0	0	2	0	0	2	2	0
Total	5	9	10	7	26	11	34	14
Percentage	36	64	59	41	70	30	71	29

to phosphate. Of the 10 plats having more than this amount only 1 responded. Responses based on the average of the tests of samples taken to a depth of 20 inches are almost identical with those secured by the Wisconsin method.

From the results secured with the three methods it would appear that phosphate deficiency cannot be accurately predicted. For fields carrying small amounts of readily available phosphate as shown by any of the methods the chances are that phosphate fertilizer will prove beneficial in about 70% of the cases. In the case of fields carrying

larger amounts, the chances of a response to phosphate are much less. There will be fields in this group, however, which will respond. There seems to be little choice so far as the method is concerned. Of the three, the Wisconsin method is slightly more reliable but is the least rapid.

SUMMARY

The Illinois, Wisconsin, and La Motte-Truog methods for the determination of readily available phosphorus were used in a study of the soils of 10 experimental fields in southeastern Minnesota upon which the responses to phosphate fertilizer were already known. Samples of soil were collected at three depths from five different locations on 116 control plats.

All samples were tested separately by the Illinois method. On two fields wide variations were found in the amount of readily available phosphorus within the same plat and in different parts of the same field, on two others the distribution was uniform, while the remaining fields showed slight variations.

There was a good agreement between the results secured by the three methods, especially between the Wisconsin and La Motte-Truog methods for which the results are expressed in pounds per acre.

The amounts of readily available phosphorus in the soils of 9 of the 10 fields were low, the surface soil carrying the least and the 20-inch level the most. The amounts in the remaining field were relatively high at all depths.

With the Illinois test, 69% of the plats testing low and doubtful responded to phosphate, while 67% of those testing medium and 27% of those testing high also responded. Using the surface soil only, the percentage of responsive plats testing low was increased slightly, but for those testing doubtful, medium, and high it was decreased.

When tested by the Wisconsin method, plats carrying 25 pounds or less per acre of readily available phosphorus at the surface responded to superphosphate in 69% of the cases and in 73% of the cases of those carrying between 26 and 50 pounds. Nine of the 10 plats carrying more than 50 pounds failed to respond.

The results secured with the La Motte-Truog test were not materially different from those secured with the Wisconsin method. The percentage of plats responding to superphosphate and carrying 50 pounds or less of available phosphorus was slightly lower, while for those carrying more than 50 pounds it was approximately the same.

Using tests of surface samples only, predictions of phosphate deficiencies would be about as reliable as when subsoil samples were

included. This would apply to all three methods, but especially to the Wisconsin and La Motte-Truog methods.

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THE DISTRIBUTION, AVAILABILITY, AND NATURE OF THE PHOSPHATES IN CERTAIN KENTUCKY SOILS[1]

M. C. FORD[2]

This investigation was undertaken for the purpose of studying the availability and nature of the soil phosphates and their distribution in the soil separates of certain Kentucky soils. The study was suggested by results reported by Roberts, *et al.* (8, 9)[3] which show in all cases a positive influence of lime on crop response to superphosphate, but both a positive and a nagative influence in the case of rock phosphate.

The nature and availability of soil phosphates have been studied by many investigators and reference to pertinent work will be given in the discussion.

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. Part of a thesis submitted at the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Also presented at the symposium on "Phosphorus" at the annual meeting of the Society held in Chicago, Illinois, November 14, 1929, and published with additions and revisions with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication September 25, 1931.

[2]In charge, Agricultural and Biological Sciences, State Teachers' College, Bowling Green, Kentucky. The writer wishes to express his appreciation for the helpful suggestions and criticisms tendered by Professor Emil Truog, under whose general supervision this investigation was conducted. He also wishes to acknowledge his indebtedness to Thomas P. Cooper, Dean and Director of the Kentucky Agricultural Experiment Station, and to Professor George Roberts, Agronomist of that Station, for the privilege of sampling the Kentucky soil experimental fields, for the use of Experiment Station records, and other data. Acknowledgments are also due J. F. Freeman of the Kentucky Station for assistance in assembling data from the Experiment Station records.

[3]Reference by number is to "Literature Cited," p. 410.

PLAN OF STUDY

The writer was fortunate in having access to the Kentucky soil experimental fields and the Experiment Station data pertaining to them. These data raised questions which suggested the desirability of conducting investigations along the following lines:

1. To study the distribution or localization in the soil separates of both the native phosphates and those formed through the application of fertilizers, for the purpose of determining in what fraction or fractions the fixation of phosphates occurs.

2. To study the nature and availability of the native phosphates in these soils.

3. To study the nature and availability of the phosphates formed when phosphate fertilizers are applied to limed and unlimed soil.

For the purposes of these studies arrangements were made to sample six of the Kentucky experimental fields. It was planned to study the nature and availability of the phosphates by means of weak acid solvents. It was also planned to make mechanical separations of the soils and to determine the phosphorus content of the soil separates.

DESCRIPTION OF FIELDS

The six experimental fields studied are located on representative areas in six of the geological divisions of Kentucky. Detailed descriptions of these divisions are given by Averitt (1) so that only a brief description of each field is given here.

Berea field. - This field was established in 1913 on DeKalb silt loam derived from Devonian shale. The organic matter content is very low, sub-surface drainage poor, and acidity strong.

Campbellsville field.—This field was established in 1919 on silt loam (not mapped) derived from Waverly shale. The organic matter content is low, drainage fair, and acidity medium.

Russellville field.—This field was established in 1913 on Decatur silt loam derived from St. Louis limestone. The subsoil is of red clay. The organic matter content is low, drainage good, and acidity medium.

Greenville field.—This field was established in 1913 on Tilsit silt loam derived from shale and sandstone of the Western Coal Basin. The organic matter content is very low, sub-surface drainage poor, and acidity strong.

Fariston field.—This field was established in 1916 on light silt loam (not mapped) derived from slaty shale of the Eastern Coal Basin. Undecomposed shale occurs in the surface and subsoils. The organic matter content is very low, sub-surface drainage poor, and acidity strong.

Mayfield field.—This field was established in 1913 on Memphis silt loam, undulating phase, of the Quaternary area. This soil is described by Jones (6). The organic matter content is low, drainage fair, and acidity strong.

SAMPLING

Samples were taken at the close of the growing season in 1927 from all of the areas except the Russellville field which was sampled in the fall of 1923. This latter field was discontinued in 1924. Samples of the surface 7 inches were taken from the check plats and from plats receiving applications of lime, superphosphate, rock phosphate, lime and superphosphate, and lime and rock phosphate.

ANALYTICAL METHODS

Mechanical analysis.—Soil separates were obtained relatively free from adhering materials through a modification of the U. S. Bureau of Soils method of mechanical analysis (4). The sand fraction was rubbed wet with a rubber-tipped pestle in a porcelain mortar. After each rubbing the sand was transferred to a beaker, water was added and after the sand settled the finer materials were removed by decantation. The silt and clay fractions were rubbed in the centrifuge tubes with a rubber-tipped stirring rod in order to break down compound particles and secure a better separation of the finer fractions. Rubbing was continued in all cases until the particles were relatively free from adhering materials, as shown by microscopic examination. The clay was divided into two fractions, *viz*., the coarse clay (0.005 to 0.001 mm) and the fine clay (0.001 mm and below).

Total phosphorus in separates.—Because the amounts of some of the separates were small it was necessary to determine total phosphorus colorimetrically. This necessitated a slight modification in the usual magnesium nitrate ignition method. The ignited mass was taken up with dilute sulfuric acid instead of concentrated nitric acid, made up to volume, filtered, and an aliquot neutralized and analyzed for total phosphorus by the modified Dénigès colorimetric method of Truog and Meyer (13).

Available phosphorus.—As solvents for available phosphorus, carbonated water and N/500 sulfuric acid buffered with potassium sulfate to pH 3.0 were used. Tests by Weyker in this laboratory showed that carbonated water dissolves 90% or more of the phosphorus in finely ground rock phosphate on prolonged extraction. Preliminary tests showed that sulfuric acid of pH 3.0 dissolves all of the phosphorus in finely ground rock phosphate in a period of 2 hours and in powdered apatite in a period of 4 hours. This solvent also dis-

solves the more readily soluble portion of the phosphorus in iron and aluminum phosphates. For a discussion of methods for readily available phosphorus, including a new method involving the use of sulfuric acid of pH 3.0, the reader is referred to a recent article by Truog (14). For extraction, 2 grams of soil were shaken with 500 cc of the solvent for a period of 4 hours where sulfuric acid was used and for a period of 24 hours where carbonated water was used. Tests showed that the amounts of phosphorus dissolved from these soils reached a maximum in these periods.

Soil reaction.—The acidity of the soil was determined by the Truog (12) zinc sulfide test.

RESULTS OF PHOSPHATE STUDIES

DISTRIBUTION OR LOCALIZATION OF PHOSPHORUS IN SOIL SEPARATES

The results obtained from the study of the distribution or localization of the phosphorus in the different fractions of soil separates are given in Table 1. Results are expressed as percentages of elemental phosphorus and as pounds per acre. The amounts of phosphorus contained in the coarser sand fractions were negligible and are not recorded.

TABLE 1.—*Amounts of phosphorus in soil separates of Russellville check and superphosphate plats.*

Soil separates	Check plat			Superphosphate plat		
	Separates %	Phosphorus %	Phosphorus Lbs. per acre	Separates %	Phosphorus %	Phosphorus Lbs. per acre
Very fine sand	15.36	0.0057	27.66	15.23	0.008	24.36
Adhering material of sand fraction	1.42	0.0547	15.53	1.42	0.1122	31.86
Silt	49.21	0.0097	95.96	50.09	0.0117	117.26
Coarse clay	11.32	0.0743	168.21	10.72	0.0982	212.68
Fine clay	18.16	0.1492	556.22	19.13	0.1592	609.11
Total	—	—	863.58	—	—	995.27

Failyer, *et al.* (4) have reported on the mineral composition of soil separates. In this study the writer has sought to determine the differences in phosphorus content of corresponding fractions of separates from the check plat and from the superphosphate plat of a representative soil. It is believed that in this manner the localization of phosphates fixed by the soil may be determined.

The results given in Table 1 show that approximately two-thirds of the total phosphorus is in the fine clay, one-fifth in the coarse clay,

and one-tenth in the silt fractions of the soils of both the check plat and the superphosphate plat. Phosphates, on being fixed by this soil, are fixed in greatest amounts by the fine clay fraction, but an appreciable amount of fixation occurs in the coarse clay and silt fractions. The adhering material from the sand fraction of the superphosphate plat contains double the amount of phosphorus as that from the check plat. Microscopic examination of this adhering material showed that it is composed largely of fine clay particles.

Availability of native phosphates.—The results obtained for the relatively available phosphorus in the soils of the six fields are given in Table 2. Crop-yield data are also given for purposes of comparison.

The amounts of phosphorus, soluble in both carbonated water and sulfuric acid of pH 3.0 in the soils of the check plats, are very small in all cases, indicating the great need of these soils of phosphate fertilization. This need is also indicated by the crop response on these soils to phosphates.

The total phosphorus content of the soils of the check plats on the different fields ranges from 650 to 1,100 pounds per acre and the amounts of phosphorus soluble in the solvents used are roughly proportional to the total phosphorus content of the different soils. These data show that little or no calcium phosphate or apatite exist in the soils of the check plats. The percentages of the total phosphorus soluble in the solvents used suggest that the nature of the native phosphates is in all cases essentially the same.

AVAILABILITY OF APPLIED PHOSPHATE

The data given in Table 2 show that wide variations exist in the availability of the applied phosphates in the different soils as revealed both by solubility studies and by crop yields. Of the factors affecting the availability of the phosphates in these soils, the source of the phosphates, the manner of application, and the solution processes in the soils are essentially the same. The amounts of phosphorus applied as superphosphate and as rock phosphate are given in Table 2, together with the percentages of the applied phosphates recoverable in carbonated water and in sulfuric acid of pH 3.0. The superphosphate used was of the 16% grade, made from Tennessee rock phosphate. It was applied broadcast, mainly after plowing, and disced in. The rock phosphate used was Tennessee rock phosphate containing approximately 30% P_2O_5 and ground for direct application to a fineness of 90 to 95% through a 100-mesh sieve.

The soils studied may be arranged into two groups according to their capacities to fix phosphates in relatively insoluble forms. The

TABLE 2.—*Solubility of the native and applied phosphates in the soils of Kentucky experimental fields in carbonated water and $N/500$ H_2SO_4 buffered to pH 3.0, together with crop yield data.**

Experimental field	Plat No.	Treatment†	Amount of phosphorus: Applied, lbs.	Amount of phosphorus: Sol. in H_2CO_3, lbs.	Amount of phosphorus: Sol in. H_2SO_4, lbs.	Percentage of applied phosphorus recovered: In % H_2CO_3	Percentage of applied phosphorus recovered: In % H_2SO_4	Average yields all series to date of sampling: Corn, bu.	Average yields all series to date of sampling: Soybeans, lbs.	Average yields all series to date of sampling: Wheat, bu.	Average yields all series to date of sampling: Clover, lbs.
Berea (DeKalb silt loam)	101	Ch	0	Trace	7.0	—	—	15.7	1,694	—	77
	102	L	0	Trace	11.0	—	—	40.6	3,591	—	751
	104	Sp	182	14.0	42.1	7.69	25.13	40.7	3,501	—	736
	105	Rp	728	145.0	315.0	19.91	43.27	39.7	3,261	—	993
	106	L-Sp	182	20.0	55.0	10.98	31.21	45.7	4,353	—	2,167
	107	L-Rp	728	320.0	430.0	43.95	59.06	45.3	4,346	—	2,083
Campbellsville (unmapped silt loam)	801	Ch	0	Trace	15.0	—	—	22.0	—	4.5	862
	805	Sp	210	11.2	37.5	5.35	17.85	46.4	—	12.2	2,690
	806	Rp	840	190.0	320.0	22.61	38.09	47.9	—	12.4	3,652
	811	L-Sp	210	13.5	50.0	6.42	23.81	51.2	—	15.7	3,672
	812	L-Rp	840	277.5	330.0	33.03	39.05	42.8	—	10.3	2,215
Russellville (Decatur silt loam)	101	Ch	0	10	18.0	—	—	28.5	1,682	8.8	1,403
	102	L	0	—	35.0	—	—	37.1	2,612	10.5	2,873
	103	Sp	140	17.5	70.0	12.50	50.00	35.4	2,438	13.7	2,387
	106	Rp	560	235.0	390.0	41.96	69.54	35.0	2,495	15.3	2,638
	107	L-Sp	140	60.0	120.0	42.85	85.71	46.2	2,715	18.3	3,533
	108	L-Rp	560	320.0	450.0	57.14	80.35	44.9	2,699	15.9	3,409

Greenville (Tilsit silt loam)	201	Ch	0	Trace	7.0	—	—	17.5	1,402	2.1	316
	202	L	0	—	12.0	—	—	29.3	2,404	6.1	1,120
	204	Sp	168	16.0	25.0	9.52	14.88	34.4	2,802	9.2	2,133
	205	Rp	672	170.0	255.0	25.15	36.46	35.6	2,944	11.0	2,478
	207	L-Sp	168	15.0	34.0	7.99	20.24	40.9	3,481	15.0	2,944
	208	L-Rp	672	255.0	340.0	37.96	50.59	37.2	3 131	11.6	2,347
Fariston (unmapped silt loam)	301	Ch	0	—	10.0	—	—	10.0	1,224	—	197
	303	L	0	—	10.0	—	—	18.4	1,986	—	467
	308	Sp	196	5.0	18.0	2.60	9.18	26.6	2,038	—	908
	305	Rp	784	130.0	400.0	16.58	51.02	34.1	2,747	—	993
	311	L-Sp	196	10.0	20.0	5.10	10.20	41.4	3,661	—	1,822
	314	L-Rp	784	340.0	460.0	43.37	58.66	28.2	2,726	—	1,215
Mayfield (Memphis silt loam)	201	Ch	0	5.0	11.0	—	—	23.4	1,818	4.6	450
	202	L	0	—	14.0	—	—	37.7	3,000	10.8	2,548
	204	Sp	168	12.0	32.5	7.20	19.34	30.8	2,587	9.5	915
	205	Rp	672	150.0	275.0	22.32	40.92	37.9	2,911	11.4	1,907
	206	L-Sp	168	30.0	81.5	17.85	48.51	44.5	3,475	17.0	3,459
	208	L-Rp	672	310.0	380.0	46.11	56.55	44.7	3,579	17.2	3,326

*Amounts of phosphorus and crop yields are given on the acre basis.
†Ch = Check; L = Lime; Sp = Superphosphate; Rp = Rock phosphate.

group of relatively low capacity consists of the Decatur silt loam at Russellville, the DeKalb silt loam at Berea, and the Memphis silt loam at Mayfield. The group of relatively high capacity consists of the Tilsit silt loam at Greenville, the silt loam formed from Waverly shales at Campbellsville, and the silt loam formed from Eastern Coal Basin shale at Fariston.

Numerous investigators have reported on the fixation of phosphates in soils. The fixation of phosphates, as measured by both water extraction and N/5 nitric acid extraction, are reported by Fraps (5). He associates the high fixation of phosphates with a high soil content of iron and aluminum oxides. He states, however, that probably only a small percentage of the total iron and aluminum oxides in soils has high fixing power.

Ellett and Hill (3) have reported on the fixation of phosphates in soils as determined by N/5 nitric acid extraction. These investigators have shown that wide variations exist in the capacities of soils to form relatively insoluble phosphates. They associate high fixing power with old soils and low fixing power with young soils.

The soils used in this study are arranged in Table 2 in the order of the relative geological ages of the parent materials of the respective soils from the oldest to the youngest. No direct correlation seems to exist between the relative ages of the parent materials and the capacities of these soils to form relatively insoluble phosphates. The active phosphorus fixing compounds which are present in these soils, the nature of which is yet to be determined, seem to be of greater significance in this respect than the extent to which weathering has progressed.

The nature of the substances in the soil which form relatively insoluble compounds with phosphorus will be discussed in a second paper. Numerous investigators have experimented with iron and aluminum hydroxides in phosphorus fixation studies. The results obtained by the writer in this study by extracting the soils with different solvents for relatively soluble iron and aluminum compounds show no direct correlation between the amounts of these compounds extracted and the activity of the soils in the formation of relatively insoluble compounds of phosphorus. Results to be reported later indicate that basic phosphates of iron and probably aluminum are formed in the soils studied. The fixation of phosphorus in these soils in relatively insoluble forms is believed to be due largely to the hydrated oxide of iron (Goethite) and possibly of aluminum.

The relative availability of superphosphate and rock phosphate to plants is shown by crop yield data given in Table 2. Where lime was

not used, the combined weights of all crops of the rotation produced on the rock phosphate plats equal with all soils and exceed with some soils the yields produced on the superphosphate plats. This superiority of rock phosphate on some soils is not believed to be due to a decrease in soil acidity produced by the application of the rock phosphate. No consistent differences in the acidity of the soils of the check, superphosphate, and rock phosphate plats seem to exist. While the rock phosphate may not have appreciably reduced acidity it may still have overcome the bad influence of acidity to some extent by raising the calcium bi-carbonate content of the soil solution so as to supply plant needs.

EFFECTS OF LIME ON AVAILABILITY

Except on check plats, ground limestone was applied broadcast to the plowed surface at the rate of 2 tons per acre for two rounds of the rotation on all of the experimental fields except the one at Fariston where three applications, or a total of 6 tons, were applied. The lime was worked into the soil.

Lime does not seem to affect the availability of the native phosphates in any of the soils studied. The small differences in the availability of the phosphorus in favor of the lime plats as compared with that of the corresponding check plats are shown in Table 2. These differences are believed to be due to the application of manure to the lime plats, and also to increased crop residues. The applications of manure and other fertilizer materials are reported by Roberts (10).

The use of lime with superphosphate aids in keeping the phosphorus in more readily available forms. However, the effectiveness of equal applications of lime in preventing the fixation of phosphorus in relatively insoluble forms differs greatly in the different soils studied. Lime is relatively effective in this respect in soils having low capacity to form relatively insoluble phosphates, but very ineffective in soils having high capacity in this respect.

The crop yields obtained from the lime-superphosphate plats are greater in all cases than those obtained from the corresponding superphosphate plats. These larger yields are believed to be due in part to the greater availability of the phosphorus in the soils of the lime-superphosphate plats of at least the Campbellsville, Greenville, and Fariston fields. Lime, when used without phosphates on these fields, does not produce very large increases in crop yields.

The influence of lime on the availability of rock phosphate differs in at least one important respect from its effect on the availability of

superphosphate. Lime tends to neutralize the soil solvents which act upon rock phosphate and, thereby, decrease its rate of solution sufficiently in certain cases, apparently, to result in a deficiency in readily available phosphorus.

The extent to which equal applications of lime to soils of the same initial acidity reduce the rate of solution of rock phosphate and its conversion to less soluble forms varies between wide limits in the soils studied. The data given in Table 2 show that more than 80% of the total phosphorus applied to the Russellville lime-rock phosphate plats is recoverable in 4 hours of extraction with sulfuric acid of pH 3.0, while only 39% of the applied phosphate is recoverable, under similar conditions, from the Campbellsville lime-rock phosphate plats.

The use of lime with rock phosphate gives a strong positive influence on crop yields on the Russellville, Berea, and Mayfield fields where the capacity to form relatively insoluble phosphates is low. On each of these three fields the combined yields of all crops produced on the lime-rock phosphate plats are approximately equal to the yields produced on the corresponding lime-superphosphate plats.

The use of lime with rock phosphate gives a very slight positive influence on crop yields on the Greenville field but a very strong negative influence in the case of the Campbellsville field. In the case of the Fariston field, the use of lime with rock phosphate gives a negative influence with corn, is without effect on soybeans, and is slightly positive with clover. On all three of these fields the crop yields produced on the lime-rock phosphate plats are distinctly less than those of the corresponding lime-superphosphate plats.

NEGATIVE INFLUENCE OF LIME WITH ROCK PHOSPHATE

Numerous investigators have studied the influence of lime on crop response to rock phosphate. Probably the most widely accepted explanation is that the lime saturates the soil solution with calcium bi-carbonate and thus greatly reduces the rate of solution of the rock phosphate, thereby creating a deficiency in readily available phosphorus.

Truog (11), working with sand cultures, has shown that plants differ greatly in their capacity to obtain phosphorus from rock phosphate. Plants having a high calcium content grow better on sand cultures receiving rock phosphate than do plants having a low calcium content. He states that the greater availability of rock phosphate in acid soils than in non-acid soils, especially for plants of low feeding power for rock phosphate, is due to the removal of the calcium

carbonate and bi-carbonate by the acid soil. The process of solution of rock phosphate is thus allowed to continue.

Bauer (2), working with sand cultures, has shown that yields of corn grown with rock phosphate may be greatly increased by leaching out at intervals the calcium bi-carbonate that has accumulated in the cultures due to the greater proportional removal of the phosphorus than the calcium by the plant. According to Bauer, the removal of the calcium bi-carbonate from the cultures permits the rock phosphate to continue to dissolve and thus provides a more adequate supply of available phosphorus to the corn plant.

TABLE 3.—*The influence of varying amounts of superphosphate and rock phosphate, both with and without lime, on crop yields on the Campbellsville field.*

Phosphate fertilizer applied per acre, lbs.	Amount of phosphorus applied per acre, lbs.	Acre yields, average of all series		
		Corn, bu.	Wheat, bu.	Clover, lbs.
Check	—	22.0	4.5	862
Lime	—	22.7	5.0	923
Sp-300*	70	36.9	7.6	1,458
Sp-600	140	38.7	7.6	1,480
Sp-900	210	46.4	12.2	2,690
L-Sp-300	70	43.5	10.7	1,956
L-Sp-600	140	45.9	8.2	2,303
L-Sp-900	210	51.2	15.7	3,672
Rp-600	280	39.8	10.1	2,176
Rp-1,200	560	44.2	—	3,312
Rp-1,800	840	47.9	12.4	3,653
L-Rp-600	280	36.8	8.4	1,662
L-Rp-1,200	560	38.6	—	2,032
L-Rp-1,800	840	42.8	10.3	2,215

*Sp = Superphosphate; L = Lime; Rp = rock phosphate.

The use of lime reduces the rate of transformation of rock phosphate in all of the soils studied in this investigation. This reduction is greater in soils where lime shows a positive influence on crop response to rock phosphate than in soils where this response is negative. As pointed out above, the negative influence of lime on crop response to rock phosphate occurs in soils having high capacity to fix phosphates in relatively insoluble forms.

At the Campbellsville field, as shown in Table 3, applications of superphosphate and rock phosphate were made in varying amounts, while lime, where used, was applied in equal amounts. The data in Table 3 show that the yields of all crops grown were increased with increased applications of both superphosphate and rock phosphate whether used with or without lime. While the use of lime produces a negative influence on crop response to rock phosphate, even with the

larger applications of rock phosphate, crop yields were increased with each succeeding increase in the application of rock phosphate. Similar data are not available for the other fields, but it is believed that the Campbellsville soil is representative of the soils on which lime gives a negative influence on crop response to rock phosphate.

From the data given in Tables 2 and 3, the writer concludes that the negative influence of lime on crop response to rock phosphate on certain soils is due to the fact that it is not sufficiently effective in preventing transformation of phosphates to relatively unavailable forms to offset the decreased solubility of the remaining rock phosphate caused by the lime. A considerable reduction in the rate of solution of rock phosphate due to lime may not result in a serious deficiency of phosphorus to crops in soils of low capacity to form relatively insoluble phosphates because in these soils larger amounts of phosphates remain in relatively available form. However, a very slight reduction in this rate of solution may produce a critical deficiency in soils of high fixing power in which the amounts of phosphates in readily available forms are less.

It has been pointed out that the effectiveness of equal applications of lime in preventing the fixation of phosphorus in relatively insoluble forms varies between wide limits in different soils. Tests conducted by the writer show that the addition of sufficiently large applications of lime to prevent fixation of phosphates in relatively insoluble forms in soils of high capacity in this respect would render these soils alkaline and thereby greatly interfere with the rate of solution of rock phosphate.

Numerous investigators have reported a critical deficiency in available manganese in certain soils to which large applications of lime are made. McHargue (7), working with pot cultures of Volusia silt loam and Dunkirk clay loam, found that applications of manganese sulfate at the rate of 5 to 10 p.p.m. to acid soils proved toxic to radishes and soybeans; that equal applications of manganese to these soils, after applying calcium carbonate at the rate of 5 tons per acre, increased the yields over those obtained from the limed soils to which no manganese was added; and that lime alone increased yields on the Volus'a silt loam but not on the Dunkirk clay loam. While no evidence of manganese deficiency has been reported for the soils studied by the writer, it was decided to study the influence of the applications of lime made to these soils on the availability of manganese for the purpose of determining whether any correlation exists between the availability of manganese and the positive or negative influence of lime on crop response to rock phosphate.

EFFECTS OF LIME ON AVAILABILITY OF MANGANESE

For extracting manganese from the soils, three solvents were used. Solvent No. 1 consisted of a 0.5% solution of potassium sulfate, an amount just sufficient to flocculate the soil as an aid to filtration.

TABLE 4.—*Solubility of manganese in various solvents in the soils of the six experimental fields.*

Plat No.	Treatment*	Pounds per acre of manganese soluble in		
		0.5% K_2SO_4	N/1 K_2SO_4	H_2SO_4 (pH 3.0)
		Berea		
101	Ch	128	197	200
102	L	44	128	240
104	Sp	190	320	360
105	Rp	150	201	240
106	L-Sp	20	64	200
107	L-Rp	57	147	300
		Campbellsville		
801	Ch	114	224	440
103	L	34	83	320
805	Sp	114	288	460
806	Rp	120	350	580
811	L-Sp	33	96	300
812	L-Rp	37	89	300
		Russellville		
101	Ch	260	448	640
102	L	65	153	500
103	Sp	288	448	720
106	Rp	260	448	640
107	L-Sp	39	102	560
108	L-Rp	104	256	720
		Greenville		
201	Ch	220	291	500
202	L	68	141	300
204	Sp	256	345	400
205	Rp	240	326	400
207	L-Sp	120	132	240
208	L-Rp	81	128	200
		Fariston		
101	Ch	280	409	600
103	L	32	76	240
108	Rp	160	320	380
105	Sp	190	205	480
111	L-Sp	38	76	140
114	L-Rp	12	38	140
		Mayfield		
201	Ch	320	460	480
202	L	40	128	240
204	Sp	300	448	400
205	Rp	300	512	460
206	L-Sp	46	147	280
208	L-Rp	22	82	280

*Ch = Check; L = Lime; Sp = Superphosphate; Rp = rock phosphate.

Five grams of soil were extracted for 2 hours in 100 cc of this solvent. Solvent No. 2 consisted of a normal potassium sulfate solution. Five grams of soil were leached on a filter with 400 cc of this solvent to remove all replaceable manganese. Solvent No. 3 consisted of N/500 buffered sulfuric acid of pH 3.0. Two grams of soil were extracted for 4 hours in 500 cc of this solvent. Aliquots of each extract were taken and the manganese content determined by the ammonium-persulfate method. The data from these studies, given in Table 4, show that the use of lime reduces the availability of the manganese in all cases. There is, however, no correlation between the reduction in the availability of the manganese and the positive or negative influence of lime on crop response to rock phosphate.

It seems reasonable to assume that the manganese extracted with 0.5% potassium sulfate solution is readily available to plants. In the case of the Mayfield lime-rock phosphate plats, where lime gives a positive influence on crop response to rock phosphate, only two-thirds as much manganese is extracted with this solvent as in the case of the corresponding plats at Campbellsville where lime gives a negative influence on crop response to rock phosphate. In the case of the Fariston soil, where 6 tons of lime were applied, the reduction in available manganese in the lime-rock phosphate plats has been greater than elsewhere. If a manganese deficiency exists in any of the soils studied it would seem likely to exist in this soil. However, no evidence of manganese deficiency has been observed in crops grown on this soil. The very great decrease in readily available manganese due to the use of lime suggests the probability of a manganese deficiency in soils to which very large applications of lime have been made. Doubtless some cases of the negative influence of lime on crop response on lime-rock phosphate plats are due in part to a manganese deficiency, especially where very large applications of lime are made. The amounts of lime used on the soils studied are not believed to be sufficiently large to produce a critical deficiency in readily available manganese. Periodic applications of lime are less likely to produce a manganese deficiency than large applications made at a single time.

Manganese seems to exist in replaceable, weak acid soluble, and relatively insoluble forms in the soils studied. The manganese which is replaced by the calcium of limestone seems to assume less soluble forms in these soils. Weak acid extraction recovers all of the displaced manganese in some soils, while in others it recovers only a part.

SUMMARY

This investigation was undertaken for the purpose of determining the nature and availability of both the native and applied phosphates in the soils of six Kentucky soil experimental fields. The influence of lime on the availability of the phosphates was also studied. The distribution or localization of the native and applied phosphates in the fractions of soil separates was determined for a representative soil for the purpose of ascertaining in what fraction or fractions of the soil separates the fixation of the applied phosphate occurs. For the relatively available phosphorus, carbonated water and N/500 sulfuric acid buffered to a pH of 3.0 were used as solvents.

Very small amounts of relatively available phosphorus were extracted from the soils of the check plats. These amounts were roughly proportional to the total phosphorus which indicates that the native phosphates are essentially of one kind in these soils. Prolonged extraction of the soils gave a solubility of the native phosphates approximately equivalent to that of dufrenite. The use of lime did not seem to influence the availability of the native phosphates.

The availability of superphosphate varies with the capacity of soils to fix phosphates in relatively insoluble and unavailable forms. On this basis, the soils studied may be divided into two groups. The first group of low capacity in this respect includes the DeKalb silt loam at Berea, the Decatur silt loam at Russellville, and the Memphis silt loam at Mayfield. The second group of high capacity in this respect includes the Tilsit silt loam at Greenville, the silt loam at Campbellsville derived from Waverly shale, and the silt loam at Fariston derived from Eastern Coal Basin shale. The use of lime reduces the rate of fixation into relatively insoluble phosphates in all of the soils, but equal applications of lime are much more effective in this respect on soils of the first group than of the second group.

The use of lime reduces the rate of solution of rock phosphate in all of the soils. This reduction is greater in soils of the first group of low capacity to fix phosphorus in relatively insoluble forms than in soils of the second group of high capacity in this respect. Lime exercises a positive influence on crop response to rock phosphate on soils of the first group and a negative or neutral influence on soils of the second group. In the soils of the second group, where a high capacity exists for fixing phosphates in relatively insoluble forms, the rate of solution of rock phosphate is also high, but a deficiency in readily available phosphorus exists, due to its rapid fixation as relatively insoluble and unavailable phosphates.

The use of lime reduces the availability of the manganese in all of the soils studied. No correlation exists, however, between the reduction in available manganese and the positive or negative influence of lime on crop response to rock phosphate. The great reduction in the availability of manganese in the case of the Fariston soil, where 6 tons of lime were applied, suggests that manganese deficiency may be responsible in part for the negative influence of lime on the phosphates where very large applications of lime have been made.

Fixation of phosphates in soils occurs largely in the fine clay fraction, but appreciable amounts are also fixed in the coarse clay and silt fractions.

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SEED SELECTION IN SUNRISE KAFIR[1]

JOHN B. SIEGLINGER[2]

Decided opinions regarding the "running out" of sorghum (*Holcus sorghum* L., *Andropogon sorghum* Brot., and *Sorghum vulgare* Pers.) seed still prevail. Popular writers often have advocated the selection of seed heads to improve the yield and other characters of grain-sorghum varieties. A simple experiment was conducted with Sunrise kafir at the Southern Great Plains Field Station, Woodward, Okla., to determine the effects of continuous selection.

EXPERIMENTAL METHODS

In the autumn of 1918, seed heads were selected from the best-appearing row in a Sunrise kafir plat, and the remaining heads were harvested and threshed in bulk. In 1919, one plat was planted in head rows with seed from individual selected heads, and another plat was planted from the bulk seed. Each year since then heads have been selected from the best-appearing head row, this continuously selected seed being the progeny of a single head planted in 1919.

Seed for a bulk plat has been obtained each year from bulk-threshed seed of the preceding crop. In the bulk plats there has been no selection, but noticeably off-type plants resulting from natural hybridization or mechanical mixture were taken out before harvest. Less than 1% of the heads were rogued each year. Heads from border rows equal to the number rogued were added to the crop from the bulk plats in order that roguing might not reduce yields.

A third plat was added to the experiment in 1920. This was planted in eight rows from as many selfed (bagged) heads. Heads in each row were bagged before blooming each season and one of the bagged heads from each row was used for planting a row the following year. The eight pure lines of Sunrise kafir have been maintained in this way for 11 years.

In 1926, a fourth kind of selection was introduced. An increase field was grown for seed each year. This increase field was kept rogued and heads were selected each season for planting the following year. Bulk seed from this field was used in the experiments. As might be expected, fewer rogues were produced in the increase field than in the smaller bulk plats.

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[2]Agronomist.

The four plats in the experiment thus were planted from seed obtained as follows:

Plat 1.—Selected open-pollinated heads from the best-appearing row of the plat each year, planted head to row.

Plat 2.—Bulk seed from the bulk plat with the natural hybrids and mechanical mixtures rogued out.

Plat. 3.—Selfed heads from each row, planted head to row.

Plat 4.—Bulk seed from a field planted from mass-selected, open-pollinated heads and rogued.

In 1919, single 10-row plats were used for the experiment. From 1920 to 1925, inclusive, the plats consisted of eight rows each. From 1926 to 1930, duplicate 4-row plats were used. Previous to 1927, the plats were a part of the grain-sorghum varietal experiments, but since then they have been in a separate block where they possibly were less subject to cross pollination with other varieties. The border rows of each plat were discarded at harvest. Except for the seed used, the plats have been handled and treated uniformly. The date of planting varied with the years from May 18 to June 18.

As in most experiments with sorghums, planting was intentionally thick. The plants were thinned to uniform stands of approximately 12 inches apart in the row when 2 to 4 inches high. The average stands obtained after thinning were very close to the intended optimum spacing of 12 inches between plants. In no plat during the experiment was the average plant spacing as close as 10 inches or as wide as 14 inches. The maximum variation in average spacing between the treatments in any one season was less than 1 inch.

Records were kept of the dates of seeding, emergence, heading, and ripening; the number of plants, stalks, and heads per row; and the average height of plants, as well as the yields of stover and grain, and the test weight per bushel of grain.

The yields and other data obtained from the experiment are shown in Table 1. The grain yields are reported in bushels per acre (56 pounds per bushel) and the stover yields in tons per acre (field cured). The field-cured weights should be comparable because all plats were of the same variety and were harvested and weighed on the same day.

RESULTS OBTAINED

The grain yields from selected heads averaged 1.5 bushels per acre higher than from bulk seed during the 12-year period. By Student's method the odds that this difference is significant are 55+ to 1. In the 11-year period the selected heads yielded an average of 1.4 bushels per acre more than the bulk seed with odds of 34 to 1 that this difference is significant. The yields from the selfed heads averaged

TABLE 1.—*Yield and other characters of Sunrise kafir grown from selected and bulk seed at the Southern Great Plains Field Station, Woodward, Okla., for the years stated.*

Source of seed	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	Average 5 years	Average 11 years	Average 12 years
Grain yield, Bushels per acre															
Selected heads	40.4	38.0	37.8	15.3	10.8	30.1	27.5	36.2	24.5	24.5	20.1	18.5	24.8	25.8	27.0
Bulk plat	38.6	35.6	38.4	12.5	8.0	25.1	24.3	36.2	22.9	23.0	22.4	19.5	24.8	24.4	25.5
Selfed heads	—	34.2	38.2	11.3	8.4	26.9	23.0	36.1	23.4	24.7	22.9	17.6	24.9	24.2	—
Increase field	—	—	—	—	—	—	—	39.8	26.1	23.0	23.1	19.4	26.3	—	—
Stover yield, Tons per Acre															
Selected heads	3.53	2.87	1.87	1.60	1.78	2.36	2.55	3.14	2.19	2.00	1.27	2.08	2.14	2.16	2.27
Bulk plat	3.37	2.32	2.11	1.56	1.74	2.17	2.19	3.46	2.35	1.99	1.48	2.28	2.31	2.15	2.25
Selfed heads	—	2.46	1.88	1.49	1.75	2.31	2.08	3.91	2.39	2.20	1.49	2.23	2.44	2.20	—
Increase field	—	—	—	—	—	—	—	3.78	2.37	1.87	1.49	1.73	2.25	—	—
Height of Plants, Feet															
Selected heads	6.0	6.1	6.7	4.7	4.6	5.7	5.7	6.3	6.4	5.3	4.8	4.4	5.4	5.5	5.6
Bulk plat	6.0	5.9	7.0	4.6	4.5	5.4	5.6	6.5	7.0	5.6	5.2	4.5	5.8	5.6	5.6
Selfed heads	—	5.9	6.7	4.7	4.6	5.4	5.3	6.5	6.8	5.6	5.1	4.7	5.8	5.6	—
Increase field	—	—	—	—	—	—	—	6.6	6.9	5.4	5.2	4.6	5.8	—	—
Heads per Plant, Number															
Selected heads	1.82	1.76	1.19	1.32	1.00	1.64	1.30	1.88	1.31	1.17	1.01	1.59	1.39	1.38	1.42
Bulk plat	1.78	1.52	1.27	1.35	1.02	1.46	1.23	1.71	1.20	1.11	0.99	1.47	1.30	1.30	1.34
Selfed heads	—	1.63	1.23	1.27	1.10	1.68	1.27	1.82	1.14	1.13	1.02	1.33	1.29	1.33	—
Increase field	—	—	—	—	—	—	—	1.93	1.27	1.12	0.99	1.50	1.36	—	—
Weight of Grain per Head, Pounds															
Selected heads	0.106	0.108	0.130	0.051	0.051	0.089	0.100	0.087	0.092	0.101	0.103	0.057	0.088	0.088	0.090
Bulk plat	0.109	0.126	0.123	0.041	0.037	0.085	0.093	0.096	0.100	0.099	0.104	0.065	0.093	0.088	0.090
Selfed heads	—	0.109	0.134	0.039	0.036	0.078	0.085	0.093	0.104	0.104	0.102	0.065	0.094	0.086	—
Increase field	—	—	—	—	—	—	—	0.096	0.102	0.098	0.109	0.064	0.094	—	—
Test Weight per Bushel, Pounds															
Selected heads	61.5	61.0	61.5	57.0	57.0	60.5	60.0	61.0	62.5	61.8	59.5	59.3	60.8	60.1	60.2
Bulk plat	61.5	61.0	61.5	56.0	56.0	60.5	59.5	61.0	62.0	61.8	59.0	59.5	60.7	59.8	59.9
Selfed heads	—	61.0	61.5	56.0	56.0	60.5	59.5	60.8	62.0	61.8	60.5	59.5	60.9	59.9	—
Increase field	—	—	—	—	—	—	—	61.9	62.0	62.0	60.0	60.0	61.2	—	—

1.5 bushels less than from the selected open-pollinated heads, with odds of 37+ to 1 that the difference is significant. There was a difference of only 0.2 bushel per acre between the average yields from the selfed heads and from bulk seed. In the 5-year period, 1926 to 1930, inclusive, the average yields from the selected heads, bulk seed, and selfed heads are nearly identical. There is, however, an average difference of about 1.5 bushels in favor of the seed from the increase field, but the odds do not indicate this difference to be significant. The experiments were conducted in duplicate plats during this latter 5-year period and may be slightly more dependable than during the earlier years.

These yields may be interpreted as indicating that selecting seed heads is preferable to using bulk seed if the bulk crop is appreciably contaminated with natural hybrids or mechanical mixtures, or if the variety shows sufficient variation to justify selection for yield. Where the crop was relatively pure and grown from selected heads, as in the increase field, the yields from bulk seed were as high as from selected heads.

As previously shown, there is a 12-year average difference in grain yield of 1.5 bushels per acre between the crop from bulk seed and that from selected heads. However, the differences were 1.8 and 2.4 bushels per acre, respectively, during the first and second years of the experiment and the comparative yields throughout the period seem to indicate that there has been no progressive improvement in the relative yields by means of head selection and no progressive decrease from using bulk seed.

The yield from the selfed heads was 3.8 bushels per acre less than that from the open-pollinated heads at the beginning of the selfing experiment in 1920. Comparison of the annual yields from the selfed heads with those from selected open-pollinated heads or from bulk seed shows that inbreeding Sunrise kafir for 11 consecutive years has not resulted in any progressive decline in yield. The yields from selfed heads during the early years, 1920 to 1925, tended to be less than from the open-pollinated heads. During more recent years, when the experiments were duplicated, the selfed heads were as productive as the open-pollinated heads.

The yields of stover from the four methods of seed selection are not appreciably different, although the plats planted from the selected open-pollinated heads produced the least stover during the latter 5-year period. These plats also had the lowest height, and possibly a short-stalked strain may have been isolated by selection at some stage in the experiment. In the plats from selected open-

pollinated heads any distinct strain would have been continued if the selections had been made from the particular head row in 1919.

The data on height in Table 1 do not indicate any appreciable differences from the methods of seed selection, except possibly in the case of the plats planted from selected heads. The data indicate that some difference existed in weight of grain per head and number of heads per plant but only minor differences in test weight per bushel of the grain. The plats from all selections headed and matured on the same days in most seasons. The crop from the open-pollinated selected heads produced more heads per plant than that from the bulk seed. The yields were thus proportionally greater because the average weight of grain per head from the two plats was the same during the 11-year and 12-year periods. Apparently a strain was isolated and continued in the plats from selected open-pollinated heads which produced more sucker heads than did the crop in the other plats.

While apparently there were some significant yield differences during the 11-year and 12-year periods, the greatest differences in the plats were in visual characters. The crop from selected heads has been the most uniform of the four selections, and the bulk seed crop has been consistently the least uniform. The crop from the increase field has been slightly more variable in both height and tillering than that from selected heads. The crop from the selfed heads has been variable in tillering, height, and maturity when considered as a plat, but the individual rows have been very uniform, being the progeny of individual selfed heads. In 1929, the crop from the selected open-pollinated heads was inferior to that from the other three selections. The environment in 1929 evidently was unfavorable for that particular selection. In 1930, the crop from selected heads was nearly on a par with the others.

SUMMARY

The four methods of selecting seed of Sunrise kafir were (1) selected open-pollinated heads, (2) bulk seed from plats, (3) selfed heads, and (4) bulk seed from increase fields.

The grain yield from selected open-pollinated heads was slightly greater than from either bulk seed from small plats or from selfed heads. This difference apparently resulted from the isolation by selection of a strain producing a greater number of sucker heads. The yield from bulk seed obtained from a relatively pure increase field was as high as from either method of seed selection.

There was no progressive increase or decrease in yield from continuous selection, from selfing seed heads, or from the continuous use

of bulk seed. The advantage in selecting seed heads in a pure variety lies chiefly in maintaining the purity and uniformity of the crop.

Some differences in the crops from the four methods of seed selection were obtained in stover yield, height of plant, number of heads per plant, weight of grain per head, and test weight per bushel of the grain.

NOTE

BEHAVIOR OF AMERICAN CORN STRAINS AND HYBRIDS IN U. S. S. R.

Visits to the Bureau of Plant Industry of the U. S. Dept. of Agriculture and to many state experiment stations and seed farms in 1930, together with attendance at the meeting of the Purnell committee on corn improvement at Lafayette, Ind., in September of that year, convinced the writer of the great significance of selfed lines and their hybrids in corn breeding. As this method is not followed generally in U. S. S. R. and as it was believed that the introduction of hybrids might be of considerable aid in the agricultural reconstruction of the country, the writer appealed to his American colleagues for samples of their more interesting hybrids for testing in U. S. S. R.

We gratefully acknowledge receipt of the following samples:

F. D. Richey, U. S. Dept. of Agr.	3
R. G. Wiggans, Cornell University	10
D. F. Jones, New Haven, Conn.	10
H. K. Hayes and I. J. Johnson, Minnesota	4
M. T. Jenkins, Iowa	12
H. A. Wallace, Iowa	20
L. J. Stadler, Missouri	13
J. F. Trost, Indiana	5
T. A. Kiesselbach, Nebraska	7
A. M. Brunson, Kansas	36
R. A. Brink and N. P. Neal, Wisconsin	12
P. J. Olson, North Dakota	1

In addition, we received from Dr. G. Will of North Dakota and Dr. W. W. Mackie of California a series of local strains which proved of great interest. Unfortunately, samples forwarded by Dr. J. R. Holbert were lost, although among samples received previously were Funk 365 and 517 and several other of Dr. Holbert's hybrids as well as hybrids from the Illinois Agricultural Experiment Station.

It is to be regretted that most of the samples arrived in June, too late for seeding. However, in order to obtain an idea of the length of the growing season of the several hybrids in comparison with our varieties, we planted the seeds in July at Sukhum, one of our southern sections, and kept an account of the number of leaves on the main stem. We attach considerable importance to this factor in determining the length of the growing season, the earlier the variety the fewer the number of leaves. On this basis all of the hybrids tested may be divided into four groups, as follows:

Group I	13 to 14 leaves
Group II	14.1 to 17 leaves
Group III	17.1 to 20 leaves
Group IV	20.1 or more leaves

According to experimental data, varieties with 13 to 14 leaves may mature in northern Ukraine, varieties having up to 17 leaves in southern Ukraine, varieties with not more than 20 leaves in northern Caucasus, while varieties with more than 20 leaves are suitable mainly for the Transcaucasus. Most of the samples belong to the third and fourth groups.

Based on these preliminary tests, the work for 1932 has been distributed over four districts, one in Ukraine, two in northern Caucasus, and one in Transcaucasus. The testing will be done with the greatest exactitude in comparison with the standard varieties for the various regions, and it is hoped that the results can be published in the fall.

Through the medium of the JOURNAL, the writer wishes to express his thanks to all who have supplied the samples.—N. N. KULESHOV, *Institute of Plant Industry, Leningrad, U. S. S. R.*

BOOK REVIEW

PLANT PHYSIOLOGY WITH REFERENCE TO THE GREEN PLANT

By Edwin C. Miller. New York: McGraw-Hill Book Co. XXIV+900 pages, illus. 1931.

There should be good reasons for the publication of any new text book in any subject; reasons plausible not only to the author, but acceptable as well to those interested in the particular field of work. Miller gives these reasons clearly in his preface, as follows:

"There has existed a need for some time for an advanced text book in plant physiology. The various texts by European investigators and teachers, while summarizing the work that has been done on the Continent, have failed to cover adequately the contributions of American and English plant physiologists. These contributions during the past two decades have been outstanding and dominate in many cases the work along certain lines. A summary of these investigations should be available to students, teachers, and investigators in plant physiology.

"It has been the aim of the author to bridge this gap in one literature and to summarize in this book the more important findings of English, American, and Continental plant physiologists. The material has been assembled in such a form as to be available as a text for upperclassmen and graduate students and at the same time to be sufficiently comprehensive as a reference book for investigators in plant physiology."

That a need has existed for a text to summarize the more important findings of English and American plant physiologists, as well as giving due consideration to the Continental physiologists, has long been recognized by teachers in the field of plant physiology. A more advanced and comprehensive text than those available has been

recognized also as a necessity. In a very large maesure Miller's new text fulfills this need.

Fourteen chapters comprise the text, as follows: The plant cell, solutions and membranes, the roots of plants, intake of water, intake of solutes, elements absorbed, loss of water, formation of carbohydrates, nitrogen metabolism, fat metabolism, digestion, translocation, respiration, and growth. The titles are merely suggestive of the content for much more is included than is suggested by the main heading. For example, under "roots" appear such subtitles as the influence of environment on roots, extent of root systems, root growth, root hairs, excretions; under water loss are included such subjects as the need of water, transpiration, the physiology of stomata, leaf temperatures, evaporation, water requirements, and the significance of transpiration.

Only one chapter is devoted to the general topic of growth, which in addition to the usual topics considered under this heading, includes dormancy and the resting period in stems, tubers, bulbs and seeds, gas injury, photo-periodism, artificial light, resistance to low temperatures, X-ray effects, and a number of other topics.

An excellent bibliography is included with each chapter. A list of questions is included in each chapter, the total number being about 700. The desirability of such a list of questions in a textbook of this character is doubtful. The various facts developed are illustrated by a large number of data clearly set forth in tabular form. Because of Prof. Miller's extended physiological studies on the more important crop plants of the Middle West more attention is given to investigations on these crops than is generally found in text books in plant physiology. This is a refreshing departure and should make the text more appealing to those in the field of agronomy as well as to plant physiologists.

It is to be regretted that so little space was devoted to growth, reproduction and light relations, dormancy in plants and seeds, tropisms, and in general what might be considered under the heading of plant response. As indicated only one-tenth of the text is devoted to these subjects. There is of course a limit to what one man can do and there is abundant evidence of much labor in the preparation of the text. And it may be stated that if any portion of the subject should be abridged it is that dealing with response rather than with those fundamental phases of metabolism which determine response.

The text should facilitate the work of all who are concerned with investigations of a physiological character. It should be of value to any concerned with the sciences of crop production and particularly it should be welcomed by those students especially interested in plant physiology as well as by teachers and research workers in this field. The book is a distinct contribution to the literature of plant physiology. (L. K.)

AGRONOMIC AFFAIRS

ANNUAL MEETING OF THE NORTHEASTERN SECTION

The annual meeting of the Northeastern Section of the Society will be held at the New York State Experiment Station at Geneva and at the New York State College of Agriculture at Ithaca on June 22 and 23. The time will be devoted chiefly to an inspection of the field work relating to agronomy at the two institutions, with the business meeting of the Section coming on the evening of June 22 at Geneva.

The summer meeting of the American Association for the Advancement of Science is to be held at Syracuse the same week, with a symposium on "Land Utilization" scheduled for June 21, which will enable many agronomists to participate in both events. Further details about the meeting of the Northeastern Section may be obtained from Dr. T. E. Odland, Kingston, R. I., President of the Section, or from Dr. M. H. Cubban, Amherst, Mass., Secretary-Treasurer.

A NEW RUSSIAN JOURNAL

A new journal of interest to agronomists and soil investigators made its appearance in Russia on January 1. The name of this journal is "Chemization of Socialistic Agriculture," and it takes the place of the former well-known journal, Zhurnal Opitnoi Agronomii (Journal of Experimental Agronomy) edited lately by Professor Gedroiz The journal is to serve the field of agricultural chemistry and especially soil chemistry, as well as agricultural (soil) physics, in contradistinction to the subject of pedology, which is covered by a special journal under that name. It is of interest to note that the Russian investigators draw a sharp distinction between pedology, or the science of the soil, and agricultural chemistry, physics, and microbiology, as applied to the soil.

The editorial board of the new journal contains such well-known names as those of Professor K. K. Gedroiz, Professor A. H. Liebiediantzev, and others. The first issue contains, among others, the following papers: The Problems of the Institute of Fertilizers in the Light of the Problems of the Second Five Year Period, by M. M. Wolf; The Present Problems of Agro-chemical Scientific Investigations, by E. V. Bobko; The Geography of Utilization of Mineral Fertilizers in the Territory of U. S. S. R., by A. H. Liebiediantzev; The Soil Absorbing Complex, Plants, Fertilization, and Soil Amelioration, by K. K. Gedroiz; The Determination of the Need of Plants and Fertilizers According to the Physiological Reactions, by D. A. Sabinin; The Microbiological Methods of Determination of the Need of Soils and Fertilizers, by W. C. Butkewitch.

Throughout the journal, an attempt is made to interpret agricultural problems in the light of socialistic principles. The heading of the journal carries the expression by Karl Marx, "Although fertility is an objective property of the soil, economically it presupposes a certain relation to the given level of development of agricultural chemistry and mechanics, and it changes together with the level of this development."

Among the news items given in the journal is one announcing the opening on January 16 in Leningrad of an All-Union Conference of General, Agricultural, and Technical Microbiology. The conference was opened by the Academician Marr, who in his speech noted the importance of microbiology in the socialistic reconstruction of agriculture and expressed the conviction that by approaching the solution of the question of the rôle of micro-organisms by means of the *dialectic* method, we will soon reach success on the "microbiological front"

A BIBLIOGRAPHY ON AMMONIUM PHOSPHATE

A bibliography of 64 titles of important articles and abstracts relating to the use of ammonium phosphate has been prepared by the American Cyanamid Company, 535 Fifth Ave., New York City, and is available in mimeographed form. The citations are complete to the end of 1931.

SPECIAL APPOINTMENTS

President P. E. Brown announces the following appointments. Prof. M. F. Morgan of the Connecticut Agricultural Experiment Station at New Haven has been named as a representative of the American Soil Survey Association on the special committee in charge of the organization of the Soils Subsection of the Society and of the program arrangements for that Subsection.

The following have been named as members of the special committee to represent the Society on the National Advisory Council on Radio in Education, with O. S. Fisher of the U. S. Dept. of Agriculture as chairman: S. C. Salmon, U. S. Dept. of Agriculture; P. H. Stewart, University of Nebraska; E. L. Worthen, Cornell University; and H. C. Rather, Michigan State College.

NEWS ITEMS

ACCORDING to an item in SCIENCE, Dr. S. A. Waksman of the Department of Soil Microbiology at the New Jersey Agricultural Experiment Station has been elected a member of the Imperial German Academy of Science at Halle in recognition of his work on the microbial population of the soil.

DR. C. H. BAILEY, Professor of Agricultural Biochemistry in the University of Minnesota and Cereal Chemist in charge of the Section of Cereal Chemistry in the Division of Agricultural Biochemistry in the Minnesota Agricultural Experiment Station, has been awarded the Thomas Burr Osborne gold medal of the American Association of Cereal Chemists for distinguished contributions to cereal chemistry. The formal presentation of the medal will be made at the annual meeting of the Association in Detroit, May 23 to 26.

TECHNICAL BULLETIN NO. 273 of the Pennsylvania Agricultural Experiment Station, under the title of "Fiftieth Anniversary of the Jordan Soil Fertility Plots," contains several of the papers in full and abstracts of others presented at the anniversary meeting at State College last June.

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THE MINERAL CONSTITUENTS OF THE COLLOIDAL FRACTION OF SOILS[1]

J. A. CHUCKA[2]

The vital importance of soil colloids in determining and governing both the physical and chemical properties of soils has made them a subject of investigation for over half a century. Much has been done in the development of methods for determining the colloidal content of soils, as well as in studying the physical and chemical properties of soil colloids. Up to the present, however, very little specific information has been obtained regarding the mineralogical composition of the colloidal fraction of soils. It was for this reason that the present study of the mineral constituents of the colloidal fraction of soils was undertaken. The colloidal fraction of soils is, of course, made up of both organic and inorganic substances. In some soils the organic substances predominate and in others the inorganic. The present study is concerned solely with the latter.

REVIEW OF LITERATURE

Several investigators give evidence as to the possible constituents in the colloidal fraction. Schloesing (8)[3] attempted a fractionation of numerous clays by different rates of settling, and from chemical analyses came to the conclusion that soil colloids are made up largely of hydrous aluminum silicates having very nearly the composition of kaolinite, namely, $Al_2O_3 2SiO_2.2H_2O$.

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. Abstract of a thesis submitted to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication September 25, 1931.

[2]Formerly Assistant, Department of Soils, University of Wisconsin; now Associate Professor of Soils, University of Maine, Orono, Me. The writer is grateful to Prof. E. Truog, under whose general direction the work was done, for the many suggestions and helpful criticisms received.

[3]Reference by number is to "Literature Cited", p. 434.

Van Bemmelen (1) subjected a large number of soils to alternate treatments with both strong and weak HCl, H_2SO_4, and NaOH solutions. He reasoned that such treatments would dissolve the colloidal fraction and would not appreciably affect the non-colloidal portion. Analysis of the dissolved material showed that the HCl and NaOH extractions dissolved varying amounts of alumina, silica, iron, lime, and magnesia. The SiO_2/Al_2O_3 ratio varied from 1 to 5. In the H_2SO_4 and NaOH extracts the alumina-silica ratio was more nearly 1 to 2, but also varied. Using a weak HCl solution, he was able to extract most of the iron from some soils, and the weak NaOH solution extracted much more alumina than silica from some soils. Hence, Van Bemmelen came to the conclusion that soil colloids consist of free silica, free iron oxide, and indefinite absorption complexes of alumina, silica, iron oxide, water, and small amounts of lime and magnesia.

Hall and Russell (3) concluded from their work that the "clay" of soils consists of a complex aluminum silicate or a mixture of several complex silicates.

Hilgard (4) extends the possible number of constituents when he speaks of "pure clay substance," humus, silicic acid, hydrated oxides of iron and aluminum, and "zeolitic hydrates." His evidence for the existence of aluminum hydroxide in the colloidal fraction is based on the fact that he obtained by acid digestion of some clay material a larger proportion of alumina than is found in kaolinite. He reasoned that no combination of aluminum and silica could be more basic than that of kaolinite and thus any aluminum in excess of that required to form kaolinite must exist as free aluminum hydroxide.

Oden (6) considered soil colloids to be made up largely of very finely divided fragments of the common soil minerals.

Robinson and Holmes (7), after an extended study of the chemical composition of soil colloids, concluded as follows: "The colloidal matter behaves as a very intimate mixture and strongly resists separation into fractions of different composition. It is probable that separate particles of different composition do not exist in the colloidal matter of soils." They pointed out, however, that it seems logical to assume that at least a small part of the colloidal matter might be composed of the ordinary soil minerals in an extremely fine state of division and that such minerals as kaolinite, nontronite, halloysite, and pyrophyllite may be present. They also pointed out that iron seems to exist in two forms in soil colloids, one as free hydrated iron oxide which gives colloids their reddish

brown color and another which does not impart color and thus must be present in some silicate combination. The former can be entirely extracted with acids, while the latter cannot.

Bradfield (2) showed that the colloidal fraction of soils consists primarily of silica, alumina, and iron oxide and that its behavior is different from that of an equivalent synthetic mixture of these three oxides.

Judging from the work of previous investigators and the work done in this laboratory, it seems logical to conclude that the mineral soil colloids are composed of an intimate mixture of hydrated alumino silicates with variable quantities of free silica, alumina, and iron oxide. The recent work on the base exchange complex of soils by Kerr (5) and by Truog and Chucka (9) has furnished strong evidence that this so-called base exchange complex is a single compound of definite composition. That being true, it would seem logical to conclude that the constituents of the inorganic fraction of soil colloids consist of a hydrated alumino-silicate possessing base exchange properties, kaolinite, free silica, free alumina, free titanium oxide, and free iron oxide.

PLAN OF INVESTIGATION

If the assumption just made regarding the qualitative mineral composition of soil colloids is true, it should be possible to determine quite accurately the quantitative mineral composition of soil colloids by means of a procedure which depends upon the possibility of extracting free silica and free alumina by boiling the soil colloid in a sodium carbonate solution without appreciably affecting kaolinite and the base exchange compound; and, furthermore, upon the possibility of accurately determining the amount of base exchange compound present in the colloidal fraction by means of a base exchange capacity determination. Preliminary work indicated that these possibilities could be realized at least partially. Details of the procedure adopted are given in the following pages.

PREPARATION OF THE PURE BASE EXCHANGE COMPOUND

In order to determine the amount of base exchange compound present in the soil colloid by means of a base exchange capacity determination, it is necessary to know the base exchange capacity of the pure exchange compound. In order to secure this information, some pure exchange compound was prepared in the following way.

Because of the high concentration of the base exchange compound in bentonite as compared with soils, the former was used as a source of the material. A sample of the raw bentonite was

powdered so that it passed a 40-mesh sieve, digested on a steam plate with 6% sodium chloride, filtered on a Buechner funnel, and washed with more sodium chloride until free of all other bases. This treatment converts the base exchange compound into its sodium salt in which state it forms a very good dispersion with water in the absence of electrolytes. The excess sodium chloride was washed out of the material with 85% ethyl alcohol, after which the material was dried to remove the alcohol and then placed in distilled water and dispersed with the aid of the Buoyoucos dispersion apparatus. After allowing the coarser particles to settle out, the suspension was passed through a super-centrifuge at such a rate as to remove all particles sufficiently large to be seen with a magnification of 430. Thus, a distinctly colloidal suspension free from unweathered minerals was obtained. This suspension was then boiled with a 2% solution of sodium carbonate to dissolve any free silica and alumina which might be present. A few grams of sodium chloride were then added and the material was allowed to digest until coagulated. When coagulated, it was allowed to settle and the clear liquid siphoned off. The coagulated colloid was transferred to centrifuge tubes, and washed, with the aid of a centrifuge, by decantation with sodium carbonate solution and finally with ammonium chloride solution to remove the sodium carbonate.

TABLE 1.—*Analysis of base exchange material from three bentonite .*

Sample	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
			Bentonite No. 1 (Wyoming)			
A	65.7	27.3	3.73	1.43	3.60	4.08
B	66.0	26.6	4.18	1.53	3.64	4.22
C	65.8	27.6	4.02	1.47	3.60	4.04
D	65.2	28.0	4.24	1.43	3.43	3.94
Average	65.67	27.37	4.042	1.465	3.567	4.07
			Bentonite No. 2 (California)			
A	67.0	28.0	1.79	3.92	3.82	4.07
B	66.7	27.7	1.72	3.94	3.84	4.08
Average	66.85	27.85	1.755	3.93	3.83	4.075
			Bentonite No. 3			
A	68.8	22.0	1.61	3.67	4.95	5.33
B	67.3	22.2	1.71	3.73	4.73	5.14
C	69.5	22.0	1.71	3.79	4.97	5.37
D	68.7	21.6	1.79	3.72	4.98	5.38
Average	68.57	21.95	1.705	3.727	4.907	5.305

Three different bentonites were used as sources of material, and the results of the analyses of the purified compound secured from these are given in Table 1. The data show that even the highly purified material still contained 5 to 6% of MgO and Fe_2O_3. Previous work (9) had indicated that the ratio of SiO_2 to Al_2O_3 in the exchange compound is as 4 to 1. The purified materials from bentonite No. 1 (Wyoming) and bentonite No. 2 (California) give ratios of these oxides which are very close to 4. The material from bentonite No. 3 (California) gave on direct treatment with hydrofluoric acid a residue which was but slowly attacked. This indicated an impurity possibly of the nature of talc or chlorite. The presence of these would account for the ratio in this case being greater than 4.

DETERMINATION OF BASE EXCHANGE CAPACITY OF BASE EXCHANGE COMPOUND

EXCHANGE METHOD

The total base exchange capacity of the purified base exchange compound, prepared as just described, was determined by both the usual exchangeable calcium method and the electrometric titration method. The procedure for the exchange method was as follows.

A sample of the pure base exchange compound in the form of the ammonium salt was saturated with calcium by repeated washing with normal calcium chloride solution by decantation in centrifuge tubes. The excess calcium chloride was then washed out with 85% ethyl alcohol, washing being continued until no test for chloride ion could be obtained. The exchangeable calcium was then replaced by repeated washing with normal ammonium chloride solution. The ammonium chloride washings were concentrated to about one-fourth of their original volume and the calcium precipitated as the oxalate and titrated wth 0.05 N potassium permanganate.

The weight of the sample used was obtained by transferring the sample, after replacing the calcium with ammonium chloride, to an ashless filter paper, drying, and igniting in a platinum crucible to constant weight.

TITRATION METHOD

To determine the base exchange capacity of the purified base exchange compound by titration, the ammonium salt of the base exchange compound was washed with 0.05 N hydrochloric acid until it was completely converted into the acid compound. This conversion was assumed to be complete when the hydrochloric acid washings no

longer gave a test for ammonia when tested with Nessler's reagent. The free hydrochloric acid was then removed by washing the acid compound with 85% ethyl alcohol until no test for chloride ion could be obtained. The alcohol was removed by transferring the acid compound into collodion sacks and dialyzing for 24 hours or more. This treatment gave a highly dispersed colloidal suspension of the acid compound. The suspension of this pure acid material was then diluted to exactly 100 cc with water, shaken thoroughly, and a 5 cc aliquot placed in a platinum crucible, evaporated to dryness, and ignited to constant weight. Thus the concentration of the suspension was obtained. The remaining 95 cc were placed in an electrode vessel in which the titration was made.

In making the titration, a hydrogen electrode was used against a normal calomel, and the E.M.F. was measured with a Leeds and Northrup type K potentiometer. The pH value of the suspension was first determined as such and then 5 grams of a neutral salt (in solution adjusted to pH 7.0) were added and the pH value again determined. The salt added was the chloride of the particular base used in the titration. The base was added from a burette, mixed with the suspension by shaking, and the E.M.F. read as soon as it became reasonably constant. Usually, the readings could be taken 5 minutes after the addition of the base. The addition of the base was continued until the pH value of the suspension reached or exceeded pH 11.00. Titration curves were drawn by plotting pH values against cc of base added. These titration curves are given in Figs. 1 and 2.

In order to determine the exchange capacity of the compound at any particular pH from these curves, it was necessary to subtract the amount of base required to bring the salt solution itself to this same pH from the amount indicated on the curve. The amount required by the salt solution was determined by means of a blank titration.

The titration curves in Figs. 1 and 2 all have the same general shape, but those for material from bentonite No. 2 are the most typical acid titration curves. This is particularly true when the material was titrated with calcium hydroxide in the presence of calcium chloride. The curves for material from bentonites No. 1 and No. 3 have a less abrupt slope through the neutral point, indicating a lower degree of activity of the material. This lowered activity may have been due to impurities in the material. The horizontal spread between the vertical portions of the curves for the material from the three different bentonites is due very largely to the fact that different amounts of material were used in titration rather than to differences in material.

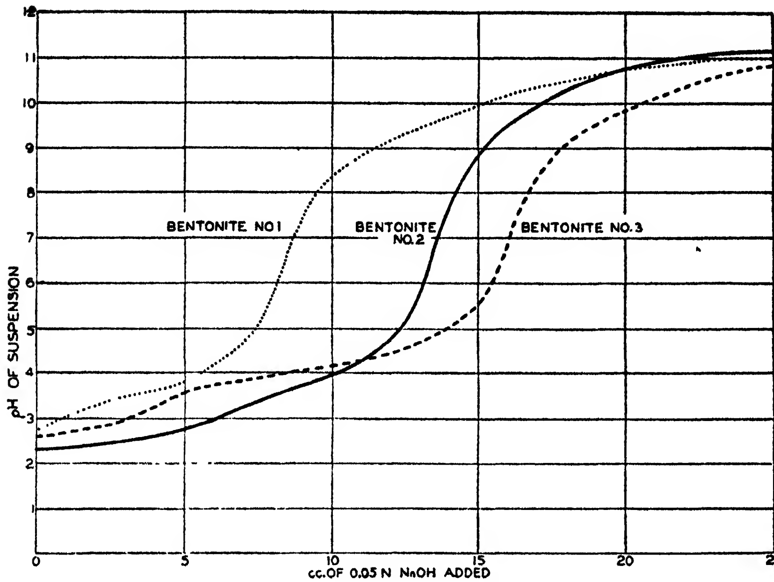

FIG. 1.—Curves showing titration of base exchange material from different bentonites with sodium hydroxide in the presence of 5 grams of sodium chloride.

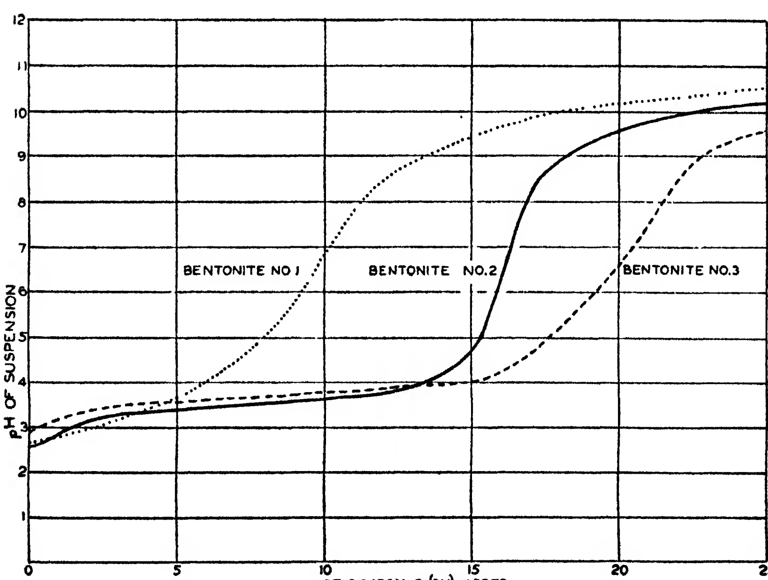

FIG. 2.—Curves showing titration of base exchange material from different bentonites with calcium hydroxide in the presence of 5 grams of calcium chloride.

For example, in Fig. 1, the amounts of the material titrated were as follows: For material from bentonites Nos. 1, 2, and 3 the amounts were 0.6593 gram, 0.6878 gram, and 0.7125 gram, respectively. In Fig. 2 the amounts were 0.5871 gram, 0.8113 gram, and 0.8208 gram, respectively. Had the same amount of material been used in all cases, the curves obtained would have been much closer together.

The base exchange capacities of the exchange compound, as calculated from the titration curves at pH values from 4.0 to 11.0, are given in Table 2. These data show that at pH 7.0 the exchange capacity is considerably lower than that obtained by the replacement method using salt solutions adjusted to pH 7.0. This apparent discrepancy may possibly be accounted for by the salt effect on the ionization of the hydrochloric acid formed. Thus, it would seem that the amount of base used up in bringing the system to a given pH is not a true measure of the amount of acid neutralized at that pH. When the system was brought to pH 10.0 or 10.5, at which point the curve has practically the same slope as that of the blank, the exchange capacity calculated from the titration curve, and corrected for the blank titration, compared quite favorably with that obtained by the exchange method.

DISCUSSION OF EXCHANGE CAPACITY

The purified exchange compound from bentonite No. 2 exhibits the same exchange capacity when measured by the titration method with $Ca(OH)_2$ and by the exchange method. The compound from the other two bentonites does not give the same value with the two methods. The titration values, in particular, are high, indicating impurities which may have interfered with the titration. If we accept the values obtained for the compound from bentonite No. 2 as being nearest the true value, we obtain after correcting for impurities an exchange capacity of 143.5 M.E. per 100 grams.

METHOD OF OBTAINING COLLOID FROM SOIL

A 500-gram sample of Colby silt loam sub-soil was digested with 500 cc of sodium chloride solution on a steam plate for about an hour. It was then filtered on a large Buechner funnel and leached with 6% sodium chloride solution until the leachate gave no test for calcium. The excess of sodium chloride was then washed out with 85% ethyl alcohol, the sample dried, placed in distilled water, and dispersed with a Bouyoucos dispersion apparatus. The sample was then separated into sand, silt, and clay fractions by means of an elutriator. The size of particles was carefully checked with a microscope. The

TABLE 2.—*Base exchange capacity of purified base exchange material determined by titration method and by exchange method, titration data taken from curves in Figs. 1 and 2.*

Bentonite from which base exchange compound was obtained	Salt added (5 grams)	Base used	Capacity in M.E. per 100 grams									
			By titration method at varying pH values									By exchange method
			pH 4.0	pH 5.0	pH 6.0	pH 7.0	pH 8.0	pH 9.0	pH 10.0	pH 10.5	pH 11.0	pH 7.0
No. 1, Wyoming yellow	NaCl	NaOH	43.2	56.9	64.5	69.8	74.3	79.0	111.0	121.0	144.0	—
No. 2, California (a) .	NaCl	NaOH	74.2	89.5	95.2	99.6	103.0	112.0	119.0	124.0	122.0	—
No. 3, California (b) . .	NaCl	NaOH	56.2	97.5	109.0	113.0	116.0	125.0	132.0	144.0	158.0	—
No. 1, Wyoming yellow	$CaCl_2$	$Ca(OH)_2$	47.7	63.4	73.5	79.7	86.0	101.0	151.0	172.0	—	114.0
No. 2, California (a) . .	$CaCl_2$	$Ca(OH)_2$	77.0	87.0	90.7	91.7	93.0	102.0	122.0	136.0	136.0	136.0
No. 3, California (b) .	$CaCl_2$	$Ca(OH)_2$	82.8	95.3	99.7	108.0	114.0	126.0	151.0	174.0	168.0	148.0

final separation of silt and clay was made with the aid of a centrifuge according to the method worked out and described by the U. S. Bureau of Soils. Both the sand and silt fractions were repeatedly rubbed with a rubber-tipped glass rod to rub off colloidal particles adhering to the coarse particles. Even after hours of rubbing, some colloidal material was found on the particles as indicated by the absorption of fuchsine and by base exchange determinations. The colloidal material rubbed off was added to the clay suspension. The clay suspension was then placed in 3-gallon carboys and allowed to settle for 60 days. The suspension was siphoned off, placed in carboys, and coagulated by the addition of calcium chloride and digestion on a steam plate. When the colloid was completely coagulated, it was allowed to settle, the clear liquid siphoned off, and the colloid washed with water containing a little sodium chloride. The latter washing was done to remove excess calcium chloride which would form calcium carbonate upon addition of sodium carbonate in the extraction of free silica and free alumina. After the removal of calcium chloride, the colloidal suspension was made up to a definite volume, and, after thorough shaking, aliquot portions of the suspension were taken for the various analyses.

The separation of the colloidal fraction from clay may be accomplished much more rapidly by the use of a super-centrifuge instead of depending on settling by gravity. If the super-centrifuge is used, the clay-colloid suspesion is allowed to enter the bowl at such a rate that most of the colloidal material[4] passes through while the clay remains in the bowl.

BASE EXCHANGE CAPACITY DETERMINATION OF SOIL COLLOID

Aliquot portions of the soil colloidal suspension were used for total base exchange capacity determinations. The exchange method of determining base exchange capacity was used as previously described for the base exchange capacity determination of the purified exchange compound.

In order to determine what the influence of boiling with 2% sodium carbonate solution, treatment with hydrogen peroxide, and grinding, wet and dry, might be on the exchange capacity of the soil colloid, samples of the soil colloid were given treatments accordingly.

[4]In this study material was considered colloidal when the particles were too small to be visible under a magnification of 430, which places the upper limit at about 0.1 micron.

In Table 3, the exchange capacities of the soil colloid before and after various treatments are given.

Boiling with sodium carbonate, treatment with hydrogen peroxide, and wet grinding have not changed the exchange capacity. Dry grinding has apparently given an appreciable increase in exchange capacity. It should be noted, however, that during the dry grinding

TABLE 3.—*Base exchange capacity of soil colloid from Colby silt loam.*

Sample No.	Treatment	Weight of sample, grams	Exchangeable calcium titration with 0.1106N $KMnO_4$, cc	Exchange capacity, M.E. per 100 grams
1	None	2.23	15.30	76.0
2	None	2.24	15.20	75.0
3	Boiled ½ hour with 2% Na_2CO_3	2.41	16.40	75.3
4	Boiled ½ hour with 2% Na_2CO_3	2.41	16.30	74.9
5	Digested 48 hours with 6% H_2O_2	1.14	7.70	74.7
6	Digested 48 hours with 6% H_2O_2	1.14	7.75	75.0
7	Wet ground in agate mortar 12 hours	1.10	7.40	74.4
8	Dry ground in agate mortar 12 hours	0.89	7.10	88.2

process, there has been an appreciable loss of material, and there may have been a lesser proportionate loss of base exchange compound than of the other constituents which would cause an increase in the exchange capacity of the residue. From the data in Table 3, it seems reasonable to assume that the exchange capacity of the soil colloid is very nearly 75 M.E. per 100 grams.

SODIUM CARBONATE EXTRACTION OF SOIL COLLOID

The free alumina and free silica in the soil colloid were determined by boiling aliquot portions of the colloidal suspension with 2% sodium carbonate solution for one-half hour. After allowing the boiled suspensions to cool, they were transferred to centrifuge tubes and centrifuged at the rate of 1,200 R.P.M. until all the colloidal material settled. The clear liquid was poured off and the colloid was

TABLE 4.—*Total analysis of Na_2CO_3 extract of colloid from Colby silt loam.*

Sample No.	Weight of sample, grams	SiO_2		Al_2O_3		Fe_2O_3	
		Grams	%	Grams	%	Grams	%
1	2.41	0.0136	0.57	0.0354	1.47	0.0003	0.012
2	2.41	0.0138	0.58	0.0352	1.46	0.0004	0.016

washed several times with 2% sodium carbonate solution. The clear extract and washings were acidified with hydrochloric acid and analysed for silica and alumina in the usual manner. The results of the analysis of the sodium carbonate extractions are given in Table 4. It will be noted that the amounts of free silica and free alumina in the soil colloid from Colby silt loam are quite small.

TOTAL ANALYSIS OF THE SOIL COLLOID

For the total analysis of the soil colloid from Colby silt loam, aliquot portions of the colloidal suspension were coagulated, filtered on ashless filter paper, dried, and ignited to constant weight in platinum crucibles. The samples were then fused with sodium carbonate and the usual method of silicate analysis was followed. The results of these analyses are given in Table 5.

TABLE 5.—*Total analysis of soil colloid from Col y silt loam.*

Sample No.	Weight of sample, grams	Grams of						
		SiO_2	R_2O_3	Fe_2O_3	TiO_2	Al_2O_3	MgO	CaO
1	1.0000	0.5567	0.4111	0.1424	0.0083	0.2604	0.0206	0.0015
2	1.0000	0.5542	0.4156	0.1430	0.0078	0.2648	0.0202	0.0015

DETERMINATION OF MINERAL CONSTITUENTS OF SOIL COLLOID

If the assumption previously made regarding the qualitative composition of the mineral constituents of soil colloids is correct, it should be possible to make a quantitative estimation of the mineral constituents from the combined results obtained from the base exchange determination, sodium carbonate extraction, and the total analysis of the soil colloid from Colby silt loam. The amounts of free alumina and free silica are obtained from the analysis of the sodium carbonate extract as given in Table 5. The percentage amount of base exchange compound in the soil colloid is obtained by dividing the base exchange capacity of the soil colloid by the base exchange capacity of the pure base exchange compound and multiplying by 100.

Taking 75 M.E. as the exchange capacity of the soil colloid and 143.5 M.E. as the capacity of the pure compound, we obtain 52.2 as the percentage of base exchange compound in the colloid of Colby silt loam. This amount of base exchange compound accounts for only about two-thirds of the combined alumina and combined silica found in the soil colloid. It was originally thought that the remaining alumina and silica might exist as kaolinite. As the work progressed, it seemed more logical to assume that the remainder of the combined

silica and alumina are found in some of the ferro-magnesium minerals of the chlorite group. The reasons for this assumption are as follows: (a) The ratio of the remaining silica to alumina is greater than that found in kaolinite. (b) Some recent work on the flocculation of different soil constituents indicated that kaolinite flocculates too readily to be found to any great extent in the colloidal fraction of soils. (c) The total analysis of the colloid gave an appreciable quantity of magnesium and iron which suggests the presence of some ferro-magnesium minerals. (d) Minerals of the chlorite group might logically be expected in the soil colloid, since they are found in abundance in soils, are very resistant, and are hydrated products arising from the decomposition of the common minerals, micas, amphibole, and pyroxene. The great variety of members in the chlorite group and the variable composition of these makes it impossible to tell exactly which ones are present.

The most important members of the chlorite group are the following:

1. Sheridanite—$3\ MgO.Al_2O_3.2\ SiO_2.3\ H_2O$
2. Corundophilite—$11(Fe,Mg)O.4\ Al_2O_3.6\ SiO_2.10\ H_2O$
3. Cronstedtite—$3(Fe,Mg)O.Fe_2O_3.2\ SiO_2.3\ H_2O$
4. Rumpfite—$7\ MgO.8\ Al_2O_3.10\ SiO_2.10\ H_2O$
5. Penninite—$5(Mg,Fe)O.Al_2O_3.3\ SiO_2.4\ H_2O$
6. Griffithite—$4\ (Mg,Fe,Ca)O.(Al,Fe)_2O_3.5\ SiO_2.7\ H_2O$
7. Stilpnomelane—$2(Fe,Mg)O.(Fe,Al)_2O_3.5\ SiO_2.3\ H_2O$

The excess amounts of combined silica and alumina, together with the magnesia and some of the iron oxide, could be made to fit either No. 6 or No. 7 by utilizing the necessary amount of iron oxide. It is also possible to shift the various constituents in such a way as to account for the presence of several members of the group.

SUMMARY

Previous work having shown that the base exchange property of the mineral matter of soil colloids is probably due largerly to one compound and that the chemical composition of this compound is $Al_2O_3.4\ SiO_2.XH_2O$, it seemed reasonable to believe that, besides this compound, mineral soil colloids consist largely of free silica. free alumina, free titanium oxide, free iron oxide, and possibly kaolinite. From a total analysis of soil colloids, an alkali-soluble alumina and silica determination, and a base exchange capacity determination, it should be possible, by calculation, to formulate a fairly accurate picture of the mineralogical composition of soil colloids. It was the purpose of the present study to investigate this possibility.

In order to make the calculation possible, it was necessary to de-

termine accurately the base exchange capacity of the base exchange compound. For this purpose samples of the purified base exchange compound were prepared from three different bentonites and the exchange capacities of these samples were determined by both the exchange method and the titration method. One of the samples gave exactly the same exchange capacity value by the two methods, and it was assumed that this sample was probably the purest. The exchange value of this sample was used, therefore, in calculations of the mineralogical composition of the soil colloid.

A sample of soil colloid was prepared from Colby silt loam subsoil and this was subjected to a base exchange capacity determination and also to the other analyses referred to. From the base exchange capacity determination, it appears that this soil colloid consists of a little more than 50% of the base exchange compound. The amounts of free silica and alumina are rather small. There exists an excess of combined silica and alumina over that required for the base exchange compound. This excess of these two oxides was not in the ratio found in kaolinite, and since other evidence did not indicate the presence of kaolinite, it was assumed that this combined silica and alumina were probably present in the form of chlorites. Chlorites are found in abundance in the weathered portion of soils and their presence in the colloid would also account for the appreciable amount of magnesia found. A portion of the iron oxide was probably also present in the chlorites. On the basis of this assumption, 30 to 40% of the soil colloid consisted of chlorites.

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ACTIVITY OF NITRIFICATION PROCESSES IN THE FALL AND WINTER MONTHS[1]

R. P. BARTHOLOMEW[2]

Conservation of soil fertility is recognized as one of the main problems confronting southern farmers. Climatic conditions make it necessary to consider the possibility of fertility losses due to biological processes which may take place during most of the year. Bacterial activity during the periods in which no crops are grown in the soils could cause the production of nitrates which might be lost from the soil.

Due to the fact that, the amount of nitrogen in most southern soils is small, it was thought that additional information on the question of the amount of nitrification taking place during the fall and winter months was desirable. The experiments were also planned to determine the usefulness of cover crops as a means of conserving available nitrogen in the soil.

PLAN OF EXPERIMENT

Analyses for nitrate nitrogen were made at intervals during the fall and winter months by Harper's modification[3] of the phenoldisulfonic acid metho l on soils from field plats at Fayetteville which had previously received different cultivation treatments. Several plats were seeded to cover crops and in the spring the material from measured areas was harvested and weighed. Total nitrogen determinations were made on this material by the modified Kjeldahl method to include nitrates in order to determine the amount of nitrogen taken up per acre by the cover crops.

It is generally accepted that bacterial activity begins in soils when the temperature is around 40°F. During the winter months at Fayetteville there are periods in which the minimum daily temperature is above 40°F, whereas the maximum daily temperature may be considerably higher. The nature of these changes can be seen from the data presented in Table 1.

The data show that these warm periods may come at any time during the winter for the data represents three 8-day periods occurring in different months in different years. The number and

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duration of these periods vary from year to year. It seems evident that the farther south, the greater the number of periods and the longer their duration.

TABLE 1.—*Maximum and minimum temperatures for the dates given at Fayetteville, Ark.*

1927	Temperature °F		1928	Temperature °F		1929	Temperature °F	
	Max.	Min.		Max.	Min.		Max.	Min.
Feb. 1	56	39	Jan. 1	67	38	Dec. 10	70	44
Feb. 2	66	44	Jan. 2	74	41	Dec. 11	75	60
Feb. 3	68	58	Jan. 3	72	37	Dec. 12	76	61
Feb. 4	72	58	Jan. 4	70	47	Dec. 13	68	60
Feb. 5	70	59	Jan. 5	72	52	Dec. 14	62	59
Feb. 6	67	49	Jan. 6	67	49	Dec. 15	60	56
Feb. 7	65	36	Jan. 7	68	50	Dec. 16	61	51
Feb. 8	56	43	Jan. 8	62	50	Dec. 17	62	36

NITRIFICATION IN WINTER

The ideal times to analyze the soils for nitrate nitrogen would have been before and after these warm periods. However, due to the obvious difficulty of anticipating the beginning and ending of these periods it was necessary to make the analyses at stated intervals. The results of the analyses for 1926, 1927, and 1929 are given in Tables 2, 3, and 4, respectively. The results for 1930 showed 1.6 and 1.0 pounds of nitrogen as nitrate in the check plats on November 14 and December 8, respectively, while the plats seeded to cover crops contained only a trace of nitrogen as nitrates.

The results of the first two seasons only, 1926-27, and 1927–28, will be discussed as the latter experiments were greatly modified but continued to determine if similar results would be obtained.

The results show specifically that nitrates have been formed during the fall and winter months. For example, the results of the analyses given for November 24, 1926, in Table 2, show more nitrogen as nitrate than was present at the preceding sampling. The increases vary from 1 to 25 pounds of nitrogen per acre. Similarly, a number of the plats contained more nitrogen as nitrates on January 20, 1927, than they contained on January 6. The results in Table 3 show in most cases a gradual building up of nitrate nitrogen in the soil. Beginning November 8, 1927, when only a trace of nitrogen was present as nitrates there was a gradual increase which reached its greatest concentration on all but two plats by January 16, 1928.

The differences in the quantities of nitrates produced may be due to several causes. In the spring of 1926 and 1927 luxuriant stands of clover were plowed under preceding the corn, whereas in all the other

TABLE 2.—*Nitrates found in Clarksville silt loam from September, 1926, to March, 1927.*

Plat No.	Previous cultivation treatment	Pounds of N as NO_3 per acre $6\frac{2}{3}$ inches													
		Sept. 1, 1926	Sept. 15, 1926	Sept. 29, 1926	Oct. 12, 1926	Oct. 28, 1926	Nov. 10, 1926	Nov. 24, 1926	Dec. 9, 1926	Dec. 23, 1926	Jan. 6, 1927	Jan. 20, 1927	Feb. 7, 1927	Feb. 19, 1927	Mar. 5, 1927
1	Medium shallow until tasselled	19.8	20.7	15.3	9.5	22.4	8.7	28.6	27.5	17.7	9.9	9.8	7.9	4.5	4.1
1A*		104.0	41.6	26.4	40.7	33.6	22.1	25.1	23.4	17.7	10.8	11.7	8.5	4.0	3.8
2A	Very shallow until tasselled	80.3	40.5	21.6	15.1	18.0	11.2	25.0	21.3	12.9	10.6	9.2	10.3	3.5	3.9
2		10.1	9.0	13.9	11.9	13.8	11.0	14.9	10.4	16.7	7.0	10.0	7.3	4.3	4.4
3	Medium deep until tasselled	11.4	10.2	9.7	9.1	8.7	T‡	18.8	21.2	13.2	9.9	9.6	8.1	4.1	3.5
3A		93.9	59.3	23.7	18.3	29.3	13.3	38.1	19.4	16.8	15.1	15.2	9.7	4.0	3.9
4A	Medium shallow until tasselled	106.8	60.5	17.8	26.9	31.5	23.9	18.9	39.8	23.3	9.9	15.5	8.9	5.3	5.5
4		18.3	18.5	16.2	11.3	17.0	8.7	16.2	11.6	11.3	10.2	11.9	9.8	4.0	3.7
5	Deep until tasselled	20.2	18.0	16.4	11.6	18.2	13.3	25.5	18.5	11.1	12.1	10.6	11.6	6.2	5.1
5A		35.3	44.7	22.4	14.8	43.9	20.5	45.2	19.9	11.7	14.1	14.0	10.4	4.8	3.8
6A	Scraped with a hoe	81.7	43.0	17.0	11.3	11.2	16.0	17.0	15.6	12.1	9.3	9.3	10.2	3.6	5.5
6		12.6	9.9	10.1	11.3	13.6	11.3	17.4	10.6	9.4	10.2	—§	9.5	3.5	3.6
7†	Medium shallow until tasselled	15.0	11.5	12.7	7.6	8.8	11.5	20.9	13.0	9.3	T	T	T	T	T
7A†		61.8	23.8	15.5	11.6	17.3	17.9	21.0	13.0	11.9	T	T	T	T	T
8	No cultivation	14.7	11.0	16.2	6.6	12.7	19.4	23.3	14.6	10.3	9.7	12.5	—‖	4.0	—
8A		23.9	8.3	14.7	46.9	16.3	11.7	15.6	14.6	15.1	9.3	8.8	—‖	4.9	3.8
9	Medium shallow until 2 feet high	41.1	13.5	15.9	12.6	23.2	15.4	19.7	22.0	15.3	10.8	9.0	—‖	4.9	4.2
9A		95.8	107.7	27.5	18.4	23.5	21.7	33.9	20.6	13.4	12.5	9.1	—‖	4.6	5.6
10A	Medium shallow until tasselled	143.2	73.4	68.4	38.0	46.8	21.9	34.8	25.0	20.4	27.0	10.8	—‖	5.0	5.4
10		24.3	13.3	17.7	trace	16.9	10.6	20.3	19.1	11.5	11.9	12.1	—‖	5.1	5.3

*The A plats in this and subsequent tables were not seeded but were given the cultural treatments indicated.

†Rye grown as a cover crop. ‡T = Too small to measure. §Sample lost. ‖Rained too hard to get samples.

TABLE 3.—*Nitrates found in Clarksville silt loam from September, 1927, to April, 1928.*

Plat No.	Previous cultivation treatment	Pounds of N as NO_3 per acre 6⅔ inches										
		Sept. 16, 1927	Oct. 7, 1927	Oct. 25, 1927	Nov. 8, 1927	Nov. 22, 1927	Dec. 6, 1927	Jan. 16, 1928	Jan. 31, 1928	Feb. 16, 1928	Mar. 22, 1928	Apr. 9, 1928
4A	Medium shallow	30.1	28.5	16.4	T	3.3	4.0	10.9	33.6	5.2	3.5	3.7
4	until tasselled...	T†	4.0	4.4	T	T	4.4	8.1	4.9	T	T	3.2
5	Deep until tasselled	T	4.0	4.3	3.8	4.2	4.2	4.5	5.1	6.0	3.5	4.0
5A		34.6	14.3	4.8	4.7	3.8	4.3	9.9	9.2	6.3	7.7	4.0
7*	Medium shallow	2.7	4.7	4.0	T	3.7	4.2	6.5	T	T	T	T
7A*	until tasselled...	20.0	7.3	7.5	T	5.6	4.6	T	T	T	T	3.6
8A	No cultivation....	T	T	2.8	T	3.5	4.7	6.5	T	5.6	4.1	4.7
8		T	T	T	T	3.2	T	6.2	T	4.6	T	3.6
10A*	Medium shallow	3.1	8.8	6.3	T	3.1	T	T	T	T	T	T
10*	until tasselled	T	3.4	2.7	T	T	T	T	T	T	T	T

*Seeded to vetch and to rye cover crops, respectively. †T = too small to measure.

TABLE 4.—*Nitrates found in Clarksville silt loam from October, 1929, to March, 1930.*

Plat No.	Treatment	Pounds of N as NO_3 per acre 6⅔ inches								
		Oct. 22, 1929	Nov. 5, 1929	Nov. 19, 1929	Dec. 4, 1929	Dec. 30, 1929	Jan. 14, 1930	Feb. 1, 1930	Feb. 17, 1930	Mar. 3, 1930
1	Check........	19.8	12.2	9.2	25.0	5.6	4.7	4.8	6.1	13.8
2	Rye cover crop.....	11.6	15.4	3.6	15.8	2.3	3.6	5.9	5.4	6.8
3	Check	37.2	12.6	11.8	24.5	6.9	8.9	17.6	13.6	18.8
4	Vetch cover crop. .	19.8	9.4	3.4	8.6	2.4	4.2	4.4	6.4	12.4

TABLE 5.—*Nitrates found in Lintonia fine sandy loam from October, 1927, to April, 1928.*

Plat No.	Treatment	Pounds of N as NO_3 per acre 6⅔ inches											
		Oct. 25, 1927	Nov. 9, 1927	Nov. 27, 1927	Dec. 6 1927	Dec. 22, 1927	Jan. 4, 1928	Jan. 16, 1928	Jan. 31, 1928	Feb. 13, 1928	Mar. 16, 1928	Mar. 28, 1928	Apr. 10, 1928
1	Rye .	T*	2.6	3.0	T	1.8	1.0	1.4	4.0	2.7	T	3.0	3.4
2	Check ...	3.2	2.8	2.8	T	1.8	2.3	2.0	4.5	3.0	3.6	3.5	5.6
3	Vetch......	4.0	4.7	3.2	T	2.0	1.9	2.2	6.1	4.4	3.4	3.6	6.0
4	Vetch......	T	3.2	T	T	1.7	2.3	1.6	4.1	T	8.9	2.9	4.6
5	Check......	T	2.5	3.8	T	2.2	3.0	2.4	5.0	3.7	4.2	4.5	6.1
6	Rye........	2.9	2.5	T	T	2.2	2.0	2.3	T	3.6	8.1	2.3	6.4

*Too small to measure.

years very sparse coverings of lespedeza and oat stubble, the result of severe droughts, were plowed under preceding the corn. The differences in the results for 1926 and 1927 are due to the differences in the distribution of the rainfall. During the summer of 1926 the rainfall was rather evenly distributed and leaching was not excessive so that by the first of September there was an accumulation of nitrates in the soil. During the early part of the summer of 1927 conditions were favorable for nitrification, and by July 22 the decomposition of the clover residue had caused an accumulation of from 100 to 200 pounds per acre of nitrogen as nitrates. On July 30 a 4-inch rainfall leached out nearly all of the nitrates so that by fall there was no accumulation of nitrate nitrogen.

In addition to the experiments at Fayetteville, one series was run at Scott which is about 150 miles farther south. The results of these experiments are given in Table 5. The results are similar to those at Fayetteville. However, the amounts of nitrates were not nearly as large due to the fact that the experiments were made on soil that had been grown to cotton for a number of years without any green manure crop being turned under preceding the cotton.

The amount of nitrates produced during the fall and winter months has been calculated by getting the sum of the increases in nitrogen as nitrates which took place from time to time. The data are given

TABLE 6.—*Nitrates produced during the fall and winter.*

Plat No.	Total pounds N as NO_3 per acre		
	Oct. 28, 1926, to Mar. 5, 1927	Oct. 25, 1927, to Apr. 9, 1928	Oct. 22, 1929, to Mar. 3, 1930
1	32.8	—	23.9
1A	3.9	—	22.0*
2A	18.2	—	28.8
2	15.1	—	15.4*
3	21.2	—	—
3A	36.0	—	—
4A	31.1	33.8	—
4	14.9	11.7	—
5	20.8	2.5	—
5A	57.2	7.5	—
6A	6.9	—	—
6	7.2	—	—
7	13.2*	11.2*	—
7A	9.4*	25.8*	—
8A	19.5	10.8	—
8	5.3	14.0	—
9	17.2	—	—
9A	16.3	—	—
10A	32.3	11.9*	—
10	26.8	3.4	—

*Does not include N in cover crops.

in Table 6. The results show that in every case nitrates were produced in the soil during the winter months. The total amounts produced per plat ranged from 3.9 to 57 pounds of nitrogen as nitrate per acre. The amounts produced in many cases were equivalent to the nitrogen in a hundred or more pounds of nitrate of soda. Retention of the available nitrogen produced in the soil during the fall and winter months could help materially to produce increased yields of the succeeding crops.

TABLE 7.—*Winter losses of nitrate nitrogen.*

Plat No.	Pounds of N as nitrates lost per acre	
	Sept. 1, 1926, to Mar. 5, 1927	Sept. 16, 1927, to Apr. 9, 1928
4A	141.5	61.4
4	29.7	12.5
5	35.9	3.0
5A	97.7	38.7
6A	82.9	
6	19.5	—
7	21.2	11.2
7A	59.3	25.8
8A	35.4	10.8
8	63.1	14.0
9	29.8	—
9A	120.4	
10A	166.5	11.9
10	46.2	3.4

The differences noted in the amounts of nitrates formed are undoubtedly due to the differences in previous cultivation treatment. The different methods of cultivation had caused differences in the physical conditions of the soils on the different plats and had permitted more weeds to grow on some than on others.

CONSERVATION OF NITROGEN WITH COVER CROPS

If nitrates are produced during the winter, losses of available nitrogen may occur unless crops are grown to conserve the nitrogen. The amounts lost would naturally vary with the amounts produced after crops stopped growing in the fall. The calculated losses for some of the plats in 1926 and 1927 are given in Table 7. The losses for 1929 ranged from 21 to 47 pounds per acre of nitrogen as nitrates.

The results show that considerable nitrates were lost in both years. In 1926, the losses ranged from 19.5 pounds to 166.5 pounds of nitrogen as nitrate per acre, whereas the losses in 1927 varied from 3 to 61.4 pounds per acre. The greater losses in 1926 were the result of late summer accumulation of nitrates and a late planting of a cover

crop. The cover crop of rye was not planted until Nov. 2, 1926, and did not become well established until the latter part of December.

No attempt was made to determine the manner in which nitrate nitrogen disappeared from the soil because of the difficulties which would be encountered in making such studies. It was assumed, therefore, that most of the loss was caused by leaching. It is also possible, however, that some of the nitrate nitrogen may have been utilized by bacteria and converted into insoluble compounds, while some may also have been lost because of denitrification processes.

TABLE 8.—*Yields and amount of nitrogen taken up by cover crops.*

Year	Location	Crop	Oven-dry matter per acre, lbs.	N content %	N per acre in tops, lbs.
1927	Fayetteville	Rye (A)	874	3.24	28.3
		Rye (B)	664	2.53	16.8
	Scott	Rye (A)	1,190	1.89	22.6
		Rye (B)	931	1.70	15.8
1928	Fayetteville	Rye	1,303	1.42	18.4
		Vetch	1,504	3.04	45.6
1929	Fayetteville	Rye	950	2.98	27.3
1930	Fayetteville	Rye	1,253	2.60	32.6
1931	Fayetteville	Rye	2,985	2.35	72.0
		Vetch	1,800	2.62	47.3

Results obtained from experiments with cover crops show that the importance of using cover crops to stop these losses of available nitrogen cannot be overemphasized. Cover crops were grown on one or more plats each year and the crop harvested from measured areas. The material was dried, weighed, and analyzed for total nitrogen and the total amount of nitrogen taken up by the tops of the plants calculated. The results are given in Table 8.

The cover crops, except in 1927, were seeded in the corn middles at Fayetteville and the cotton middles at Scott during the last half of September and were harvested before the middle of March. The rye in 1927 was not seeded until Nov. 2. Vetch was killed out in these experiments in 1929 and 1930.

The results show that cover crops prevent the loss of large amounts of available nitrogen. The amounts saved at Fayetteville varied from 16.8 to 72 pounds of nitrogen per acre. The nitrogen taken up by both the rye and vetch was probably either in the ammoniacal or nitrate form, although the possibility exists that the vetch may have fixed some atmospheric nitrogen. The use of the rye and vetch cover crops therefore prevented the loss of available nitrogenous fertilizers. The efficiency of cover crops as a means of conserving available nitrogen in the soil can be seen from an examination of the

data in Tables 2 to 5, inclusive. These data show that after the cover crops became established only a trace of nitrogen as nitrate was found in most of the soils seeded to cover crops. Much of the nitrogen taken up by the cover crop would be available to the succeeding crop shortly after the cover crop was turned under.

SUMMARY

Results of experiments to determine whether nitrification takes place in soils which are subjected to cold periods with intermittent warm periods are reported. Studies to determine the value and efficiency of cover crops are also reported. The results may be summarized as follows: (1) Nitrates were produced in soil during the fall and winter months; (2) relatively large amounts of nitrates disappeared from soils not planted to cover crops; and (3) cover crops are efficient means of preventing loss of soluble nitrogenous compounds from the soil.

THE PERIODISM OF NITROGEN FIXATION IN SOILS AND THE INFLUENCE OF INOCULATION WITH AZOTOBACTER[1]

L. G. THOMPSON, JR.[2]

In most experiments conducted to ascertain the beneficial effects of inoculation of soils, determinations have been made of the quantity of nitrogen in the soil before and after a period of incubation varying from a few weeks to several years. In some instances large gains in the nitrogen content have been secured, in other cases small increases have been noted, while in still other experiments there has been a loss of nitrogen from the soil. This suggests the possibility that there may be periodic cycles in which nitrogen fixation is followed by a loss of nitrogen from the soil. There may also be periods of rapid fixation followed by periods of slow or practically no fixation. This is probably one of the reasons why some investigators have secured good results and others poor results from the inoculation of soils with Azotobacter.

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HISTORICAL

Soil inoculation was first attempted by Caron (3).[3] He prepared cultures of certain bacteria which, when inoculated into the soil, generally increased crop yields.

Stoklasa (15) was one of the first to study the commercial preparation "Alinit" which was put on the market as a result of Caron's work. He claimed that it led to the fixation of nitrogen in considerable quantities. Sewerin (14) also studied the preparation and found that it contained two organisms, *B. ellenbachensis* a and b. Many tests of Alinit were made but with negative results, and the conclusion was finally reached that it had no practical value.

When Beijerinck discovered the aerobic, free-living nitrogen fixers to which he gave the generic name Azotobacter, attention was again called to the possibility of inoculating soils in order to increase their nitrogen content and thereby improve their crop-producing power.

Vogel (16) grew mustard and oats in pots containing soils treated with dextrose and various quantities of sodium nitrate, inoculating part of the soils with a pure culture of *Azotobacter chroococcum*. He secured increased yields on the inoculated soils, but the soils receiving sodium nitrate gave the largest yields. The experiment was repeated in the field, but with negative results.

Lipman and Brown (12) inoculated soils in cylinders in the field with pure cultures of *Az. vinelandii* and *Az. beijerinckii*. The soils were kept bare the first year and then were cropped to a rotation of oats, corn, and rye. They found considerable variation in the yields and nitrogen content of the crops, but reached the conclusion that the inoculation did not increase the nitrogen supply of the soil.

Emerson (4) made some rather extensive studies on the subject of soil inoculation with Azotobacter and concluded that soils may be profitably inoculated with Azotobacter. The best results were secured with *Az. vinelandii* and *Az. beijerinckii*. He compared the effects of decaying oat straw and clover hay on Azotobacter and found that the straw was more stimulative to nitrogen fixation than clover hay.

Makrinoff (13) carried out some preliminary experiments on the inoculation of virgin peat soils with Azotobacter and reported that increases in crop yields were secured by inoculation.

Brown and Hart (2) carried on soil inoculation studies with pure cultures of *Az. chroococcum*, *Az. vinelandii*, and *Az. beijerinckii* and found that the nitrogen content of the soil was increased when cropped to wheat, but the yield of wheat was not increased.

[3]Reference by number is to "Literature Cited", p. 451.

Zucker (18) inoculated soils with a commercial culture, "Nitrofer", prepared by the Azotogen Institute, Dresden, but obtained no increases in the yields of barley, mustard, or radishes.

Gains of nitrogen in soils have been measured in several instances. Hall (9) noted an annual increase of 100 pounds of nitrogen on Broadbalk field and 25 pounds on Geescroft field.

Voorhees and Lipman (17) carried on pot experiments with a soil containing 5,000 pounds of nitrogen per acre to a depth of 1 foot, and noted an increase of about 1,600 pounds of nitrogen in two seasons.

Greaves (7) analyzed many soils in Utah and found that the average nitrogen content of the soils which had been growing wheat and other non-leguminous crops for from 20 to 50 years was 0.2009%, whereas in adjacent virgin soils there was only an average of 0.1984% of total nitrogen.

Fulmer (6) noted a gain in total nitrogen in a field soil and also in a garden soil, but the increase was greater in the field soil due perhaps to the presence of a greater number of nitrogen-fixing bacteria.

Greaves and Nelson (8), in field experiments, found that an application of 5 tons of manure to a calcareous soil yearly, over a period of 11 years, increased the nitrogen content of the soil by 1,370 pounds, which was 486 pounds greater than the nitrogen added in the manure.

In laboratory experiments, Hutchinson (11) found that 6 mgm of nitrogen were fixed per gram of plant residues added to the soil, while in pot experiments gains of 9 mgm per gram of residues were secured.

Batchelor and Curie (1) analyzed incubated soils for total nitrogen, including nitrates, at intervals of 2 weeks and found that there was a gain in nitrogen content and then a loss followed by a similar gain and then a loss of nitrogen. It was concluded that when a single incubation period is used in nitrogen fixation experiments a good measure of the nitrogen-fixing power of soils is not obtained.

The purpose of the work reported here was to determine whether or not a cycle of nitrogen fixation and loss of nitrogen occurs in normal soils, and to determine the effect of inoculation with Azotobacter and of fertilizer treatments on this cycle Also, to determine whether there is such a cycle in sterilized soil inoculated with Azotobacter.

METHODS

LABORATORY STUDIES

One hundred grams of Clarion loam were placed in each of 20 500-cc Erlenmeyer flasks. The flasks of soil were sterilized and 10 of them inoculated with *Az. chroococcum.*[4] The other 10 flasks were

[4]This species was secured through the courtesy of N. R. Smith of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture.

not inoculated and served as checks. The flasks were incubated at room temperature for 2, 4, 8, and 10 weeks. At the end of each incubation period the total nitrogen was determined by the modified Kjeldahl method. In order to prevent a loss of nitrates from the soil a modification of the salicylic acid method (5) was used.

GREENHOUSE STUDIES

Fifteen pounds of Clarion loam in each of 10 2-gallon glazed pots were treated as follows:

Pots 1 and 2—Check.
Pots 3 and 4—Inoculated with *Az. chroococcum.*
Pots 5 and 6—Inoculated with *Az. chroococcum* and treated with straw.
Pots 7 and 8—Inoculated with *Az. chroococcum* and treated with straw and superphosphate.
Pots 9 and 10—Inoculated with *Az. chroococcum* and treated with straw, superphosphate, and sodium nitrate.

Oat straw was applied at the rate of 3 tons per acre, or 20.41 grams per pot. Superphosphate (20 %) and sodium nitrate were applied at the rate of 200 pounds per acre or 0.68 gram per pot. Each pot was inoculated with 300 cc of a 6-day culture of *Az chroococcum.* A test of the inoculum showed the presence of a vigorus growth of Azotobacter.

The soils were sampled every 2 weeks, and the total nitrogen, including nitrates, was determined by the modified Kjeldahl method (5)

Nitrates were determined every two weeks by the phenol-disulfonic acid method as modified by Harper (10).

After the first 4 weeks, the numbers of Azotobacter were determined every 2 weeks until the end of the experiment.

One gram of dry soil was distributed evenly over the surface of nitrogen-free mannitol agar plates. The numbers of Azotobacter colonies developing on a section of the plate were counted after 2 to 4 days.

RESULTS

Table 1 shows the total nitrogen content of Clarion loam after various periods of incubation at room temperature. The nitrogen content of the sterile soil inoculated with Azotobacter increased rather rapidly for the first 4 weeks. Then, there was a slight decrease in nitrogen followed by another increase and then another slight decrease. There was some variation in the nitrogen content of the check soils, but this was no doubt due to the experimental variation

in sampling the soil and in making the determinations. These results indicate that the growth of Azotobacter in soil tends to be rapid at first, then there is a period of no growth followed by another period of vigorous growth.

Table 1.—*The total nitrogen content of Clarion loam after certain periods of incubation at room temperature.*

Treatment	Mgm of N per 100 grams of soil*					
	At beginning	After 2 weeks	After 4 weeks	After 6 weeks	After 8 weeks	After 10 weeks
Sterilized......	205.2	206.3	209.2	212.4	212.7	209.0
Sterilized and inoculated with *Az. chroococcum*	205.2	219.8	227.6	224.3	233.1	231.3

*Average of duplicate flasks.

Table 2 shows the total nitrogen content of the soils in pots in the greenhouse with various fertilizer treatments. In the untreated soils there was a rapid gain in total nitrogen for the first 2 weeks which was followed by a slight decrease in nitrogen, then a slight increase and finally a large decrease so that at the end of the experiment the soil contained about the same quantity of nitrogen as at the beginning. In the soil inoculated with Azotobacter, the nitrogen content followed a similar cycle, but there was a little more nitrogen in the soil at the end than at the beginning of the experiment. The soils which were treated with oat straw and inoculated with Azotobacter made larger

Table 2.—*The total nitrogen content of Clarion loam in pots in the greenhouse with various fertilizer treatments.*

Treatment	Mgms of N per 100 grams of soil*							
	Feb. 8	Feb. 22	Mar. 8	Mar. 22	Apr. 5	Apr. 19	May 3	May 17
Check .. .	215.3	231.3	229.2	226.3	233.6	222.5	224.1	213.9
Inoculated with *Az. chroococcum* .	218.3	231.7	221.2	225.1	231.5	228.5	220.1	221.3
Inoculated with *Az. chroococcum* +straw	223.4	232.2	223.8	239.6	236.4	239.6	227.3	225.2
Inoculated with *Az. chroococcum* +straw +superphosphate .	220.8	229.3	224.2	232.7	235.5	232.8	231.6	232.2
Inoculated with *Az. chroococcum* +straw +superphosphate +$NaNO_3$.........	221.7	228.1	224.1	224.8	233.8	241.8	238.2	234 4

*Average of duplicate pots.

gains in total nitrogen, but they also lost more nitrogen, so that the total nitrogen content at the end of the experiment was not much higher than that of the untreated soil. The soils treated with straw and superphosphate did not show such large increases or decreases in nitrogen content, but they contained considerably more nitrogen at the end than at the beginning of the experiment. When sodium nitrate was added with the other treatments, there was not much variation in total nitrogen content for the first 6 weeks, then there was a gradual increase and finally a slight decrease.

While these results do not show definitely that there was a cycle of nitrogen fixation and denitrification, they do indicate that such was the case in uncropped greenhouse soils. Fig. 1 shows the curves for the different treatments. The variations in the curves are probably due to sampling the soil and making the chemical determinations, but the general trend of the curves seems to be significant. It indicates that there was not a continuous fixation, but instead a vigorous fixation for a time followed by a period of little or no action. During this latter period the ammonifiers and probably even the denitrifiers were active, for there was a loss of nitrogen either as ammonia or free nitrogen, and there may have been some nitrogen lost in both of these forms.

Table 3 shows the nitrate content of the soils in pots in the greenhouse under various fertilizer treatments. In the soils which were inoculated with *Az. chroococcum* there was a large decrease in nitrate

TABLE 3.—*The nitrate nitrogen content of Clarion loam in pots in the greenhouse under various fertilizer treatments.*

Treatment	Nitrate nitrogen in p.p.m.*							
	Feb. 8	Feb. 22	Mar. 8	Mar. 22	Apr. 5	Apr. 19	May 3	May 17
Check	21.2	23.9	30.5	30.6	34.9	41.2	46.5	45.3
Inoculated with *Az. chroococcum*	10.1	17.9	18.6	23.5	33.9	34.4	39.3	32.7
Inoculated with *Az. chroococcum* + straw	1.0	1.5	5.1	7.1	17.7	18.0	24.5	32.4
Inoculated with *Az. chroococcum* + straw + superphosphate	1.1	1.3	3.9	5.5	14.8	13.2	21.1	22.9
Inoculated with *Az. chroococcum* + straw + superphosphate + $NaNO_3$	5.4	5.7	16.8	21.6	35.2	36.7	42.8	43.9

*Average of duplicate pots.

content after 2 weeks which was no doubt due to nitrate assimilation by the Azotobacter. The nitrate content continued to be lower in the inoculated than in the uninoculated soils up to the end of the experiment. These results indicate that in soils containing considerable nitrate nitrogen the Azotobacter assimilate the nitrate nitrogen in preference to the free nitrogen.

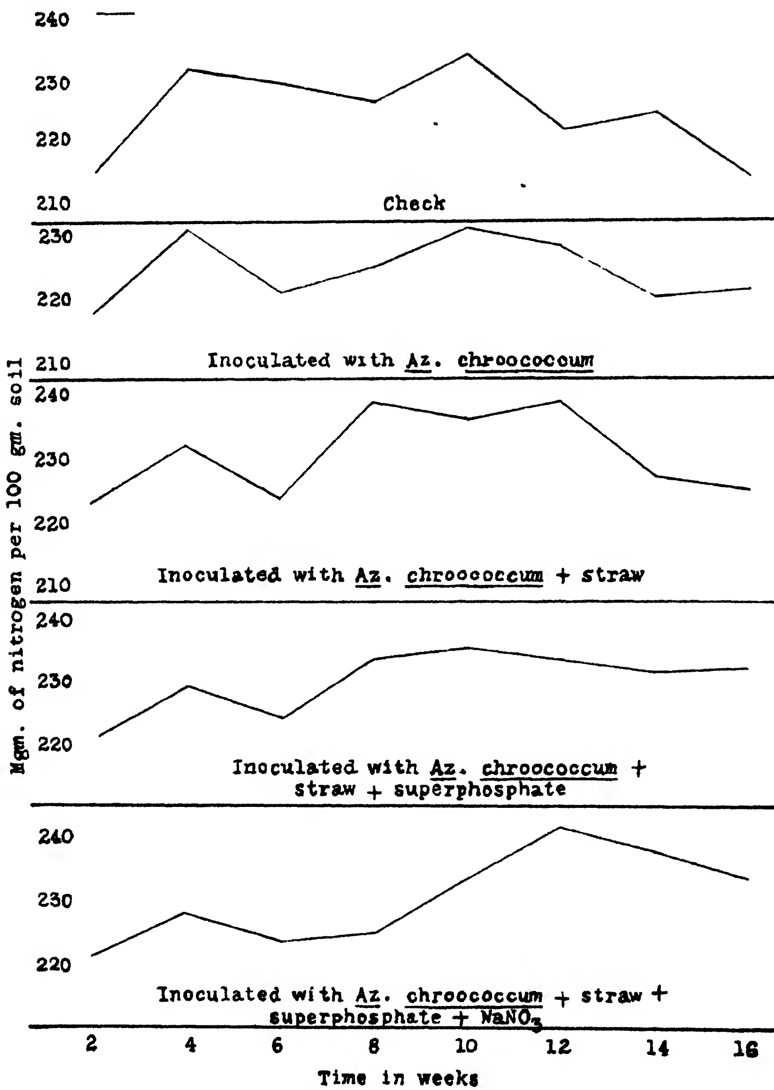

FIG. 1.—The total nitrogen content of Clarion loam in pots in the greenhouse with various treatments.

In all the soils treated with straw there was a great decrease in nitrate nitrogen which continued until near the end of the experiment, when there was almost as much nitrate nitrogen as in the soils not treated with straw. In the soils treated with sodium nitrate, straw, and superphosphate there was not as large a decrease in nitrate nitrogen. The quantity of nitrate was practically the same after 6 weeks as in the untreated soils inoculated with Azotobacter; and at the end of the experiment, the nitrate content was as large as in the

TABLE 4.—*The numbers of Azotobacter in Clarion loam in pots in the greenhouse with various fertilizer treatments.*

Treatment	Number per 100 grams of dry soil*					
	Mar. 8	Mar. 22	Apr. 5	Apr. 19	May 3	May 17
Check	0	0	0	0	100	400
Inoculated with *Az. chroococcum*	45,000	40,000	71,000	35,000	48,000	81,500
Inoculated with *Az chroococcum* + straw	41,000	17,000	67,000	84,000	39,000	41,500
Inoculated with *Az. chroococcum* + straw + superphosphate	39,000	13,000	57,000	53,000	21,500	22,000
Inoculated with *Az. chroococcum* + straw + superphosphate + $NaNO_3$	49,000	60,000	77,500	78,500	36,000	39,000

*Average of duplicate pots.

check soils. There was less nitrate nitrogen in the soils treated with straw and superphosphate than in the soils treated with straw alone. This seems to indicate that the phosphates must have stimulated the nitrate-assimilating bacteria and also the Azotobacter to use more of the nitrates.

Table 4 shows the numbers of Azotobacter in the soil in pots in the greenhouse with various fertilizer treatments. In general, there was a smaller number of Azotobacter in the soil receiving straw and no nitrate than in any of the other inoculated soils. This was especially true on March 22, and that condition seemed to be approached again on May 3 and May 17. At the other dates of sampling there was not a very large difference, except on April 5 and April 19, when there was a rather large increase in the numbers of Azotobacter with all the treatments.

DISCUSSION

In general, the results indicate that there is recurrent periodism of nitrogen fixation and denitrification in uncropped soils which

extends over a period of 10 to 14 weeks. This cycle may not take place in cropped soils, as the plants would use the nitrates and in some cases even the ammonia, thus preventing losses.

When the nitrate content is compared to the total nitrogen supply in the soils, there seems to be some correlation. The soils which were lowest in nitrate nitrogen made the largest gains in total nitrogen. This seems to indicate that the nitrogen fixers prefer nitrate nitrogen but will use free nitrogen when it is necessary. There is also a correlation between the numbers of Azotobacter and the nitrate content of the soils. The inoculated soils which were lowest in nitrate nitrogen also contained the smallest numbers of Azotobacter. This indicates that the Azotobacter may make a greater growth in soils containing considerable nitrates, using the nitrates instead of free nitrogen. The greater growth in the case of the soils treated with sodium nitrate, straw, and superphosphate was probably due to the fact that there were three materials added which were stimulative to growth.

Generally, the total nitrogen content was somewhat higher in the soils receiving the fertilizer treatments than in the untreated soils. The straw was the first to stimulate nitrogen fixation, but at the end of the experiment the combination of straw, superphosphate, and sodium nitrate was stimulative to nitrogen fixation.

SUMMARY AND CONCLUSIONS

In the experimental work reported here studies were made on soils in the greenhouse and also on sterile soils kept in the laboratory to determine whether there was a cycle of nitrogen fixation and denitrification in soils; and to determine the effect of inoculation with *Az. chroococcum* and of fertilizer treatments upon this cycle, the nitrate content, and the numbers of Azotobacter in the soil.

There was a gain in total nitrogen and then a loss in nitrogen in the greenhouse soils. The addition of straw greatly reduced the nitrate content of the soil, but as the experiment proceeded the nitrate content increased until it was practically the same as that of the untreated soils. The depressing effect of straw on the nitrate content of the soil was relieved to some extent by the addition of sodium nitrate.

Inoculating the soil with *Az. chroococcum* caused a considerable reduction in the nitrate content of the soil. The soils which were lowest in nitrate nitrogen generally made the largest gains in total nitrogen. In general, the soils which were lowest in nitrate nitrogen contained the smallest numbers of Azotobacter.

The addition of straw alone and with superphosphate increased the amount of nitrogen fixed in the soils. Sodium nitrate depressed nitrogen fixation at first, but at the end of the experiment there was considerable fixation.

In the sterile soils inoculated with *Az. chroococcum* there was a gain in total nitrogen, then a slight decrease, followed by another gain.

The results seem to indicate that there is a cycle of nitrogen fixation and denitrification in uncropped soils.

Azotobacter seem to prefer fixed nitrogen in preference to free nitrogen, but will use free nitrogen when there is a deficiency of fixed nitrogen. The nitrogen content of uncropped soils may be increased by the inoculation with Azotobacter and the addition of some suitable carbohydrate to the soil.

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A COMPARISON OF THE NIKLAS AND TRUOG METHODS FOR THE DETERMINATION OF AVAILABLE PHOSPHORUS IN SOILS[1]

F. B. Smith, P. E. Brown, and F. E. Schlots[2]

It has long been recognized that there is a difference in the availability of phosphorus in various soils, but in spite of the fact that many attempts have been made to develop a method which would indicate the amount of the element in an available form in a soil, no satisfactory method has yet been devised. If this could be done it would be possible to determine the phosphorus needs of the soil and the problem of phosphorus fertilization would be much simplified. Apparently, however, the most that any method suggested will accomplish is to indicate changes in the amount of readily available phosphorus in a soil under more or less definite, fixed conditions.

Niklas, Poschenrieder, and Trischler (3)[3] used the growth of *Aspergillus niger* in culture solutions to which soil had been added as an indication of the phosphorus needs of the soil and obtained quite satisfactory results, there being a rather close agreement with the results secured by the Neubauer method. Previously, Brown and Smith (1) had found that the ability to assimilate phosphorus is rather common to molds, and according to Dox (2) *A. niger* requires phosphorus for its development. Hence, the growth of this mold under suitable test conditions should indicate the amount of readily available phosphorus in the soil Truog (4) used 0.002 N sulfuric acid, buffered with ammonium sulfate to a pH of 3.0, to extract the readily available phosphorus from the soil.

The purpose of this work was to compare the phosphorus needs of the same soils, as determined by the method of Niklas, Poschenrieder, and Trischler with the amount of readily available phosphorus in soils variously treated as determined by the Truog method.

PROCEDURE

The A horizon of an acid Tama silt loam was selected for the study. The soil was taken to the greenhouse where it was pulverized and sieved through a ¼-inch sieve. A sample was taken at this time and the lime requirement determined by the Truog method. The

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Journal paper No. B4 of the Iowa Agricultural Experiment Station. Received for publication October 12, 1931.

[2]Research Associate Professor, Acting Head of Department, and Fellow, respectively.

[3]Reference by number is to "Literature Cited," p. 459.

treatments made in duplicate 4-gallon pots are shown in Tables 1 and 2. The moisture content of the soils was adjusted to 24% by additions of distilled water and maintained at 22 to 24% throughout the experiment. The soils were sampled after 6 and 12 weeks for determination of the available phosphorus by the two methods.

TABLE 1.—*The growth of A. niger in Tama silt loam under various soil treatments.*

Treatment	Mgm of mycelia	
	After 6 weeks	After 12 weeks
Check	263.6	257.9
3 tons lime per acre	272.4	287.8
6 tons lime per acre	302.5	285.6
120 lbs. 20% superphosphate per acre	297.4	261.5
3 tons lime + 120 lbs. superphosphate per acre	314.9	251.0
6 tons lime + 120 lbs. superphosphate per acre	325.7	282.9
78 lbs. rock phosphate per acre	249.8	241.2
3 tons lime + 78 lbs. rock phosphate per acre	236.4	248.9
6 tons lime + 78 lbs. rock phosphate per acre	343.4	247.2
1,000 lbs. 300-mesh rock phosphate per acre	369.5	307.2
3 tons lime + 1,000 lbs. 300-mesh rock phosphate per acre	387.9	350.5
6 tons lime + 1,000 lbs. 300-mesh rock phosphate per acre	388.1	346.6

In the tests using the Niklas, Poschenrieder, and Trischler method cultures of *A. niger* were grown in 200-cc Erlenmeyer flasks containing 7 grams of the soil and 60 cc of a nutrient medium containing 1.0% citric acid, 0.6% ammonium sulfate, 0.1% peptone, and 0.012% potassium sulfate. The phosphorus necessary for growth was supplied by the soil. This medium was inoculated with a 1-cc suspension of *A. niger* spores and the cultures incubated 4 days at 35°C, after which the mycelium was removed and weighed according to the procedure outlined by Niklas, Poschenrieder, and Trischler. The results secured are given in Table 1.

The available phosphorus was determined by the Truog method as previously described and the results secured presented in Table 2. The data are shown graphically in Figs. 1 and 2.

RESULTS WITH *ASPERGILLUS NIGER* METHOD

The growth of *A. niger* was stimulated by the lime treatments of the soil tested as is indicated in Table 1. With the soil receiving 3 tons of lime per acre there was an increase in growth of 8.8 mgm over that secured with the check soil. The growth was still greater with the soil which received 6 tons of lime per acre, an increase of 39.9 mgm being shown over that obtained with the check soil.

When the soil treated with superphosphate was tested, the growth of *A. niger* was increased 33.8 mgm over that secured with the check

soil. The soil receiving 3 tons of lime per acre with the superphosphate gave an increased weight of mycelial growth of 42.5 mgm over that obtained with the check soil, showing a distinct effect of the lime on the availability of the phosphorus. With the soil which received 6 tons of lime per acre with the superphosphate there was also an increased growth of *A. niger* over that with the check soil.

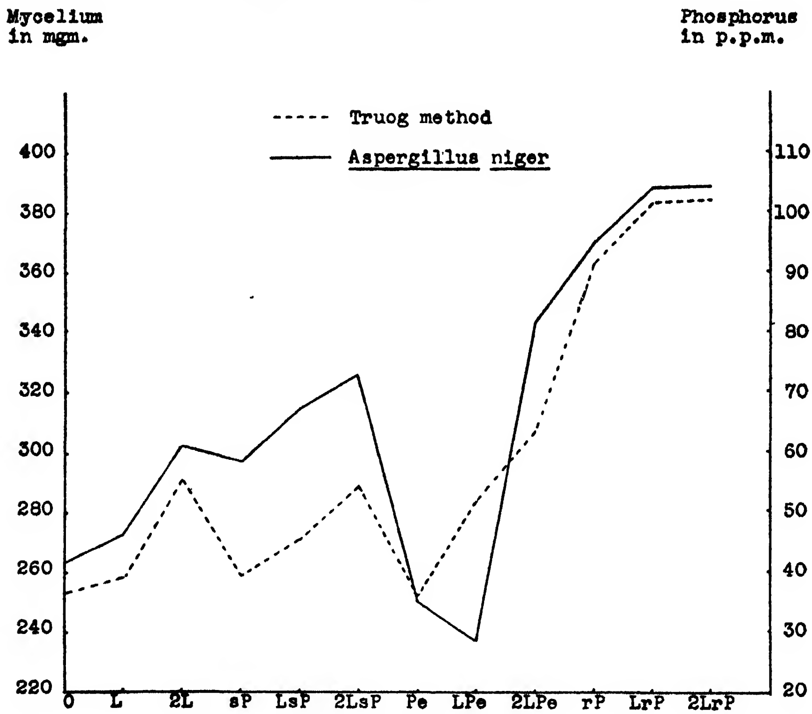

FIG. 1.—Available phosphorus at 6 weeks by different methods.

However, the increase with this soil was only 23.2 mgm. The 3 tons of lime with the superphosphate apparently had the greatest effect on the availability of the phosphorus according to this method.

The phosphorus in the rock phosphate applied to the soil at the rate of 78 pounds per acre was apparently soluble in the citric acid in the medium to only a limited extent and was less available to *A. niger* than that in the superphosphate. This difference in the availability of the phosphorus was indicated by a decrease of 13.8 mgm in the weight of mycelial growth. When the soil treated with 3 tons of lime and the 78 pounds of rock phosphate per acre was tested, there was less mycelial growth than with the soil receiving only the 3 tons of lime. A decrease of 36.0 mgm in the weight of mycelial growth was

shown in this case. With soil receiving 6 tons of lime with the 78 pounds of rock phosphate per acre the growth of the mold was greater than that obtained with the soil treated with the 6 tons of lime alone.

When soil treated with 1,000 pounds per acre of rock phosphate was tested, there was a stimulation in the mold growth, an increase of 105.9 mgm over the weight of growth with the check soil being obtained. With the soil receiving 3 tons of lime per acre with the rock

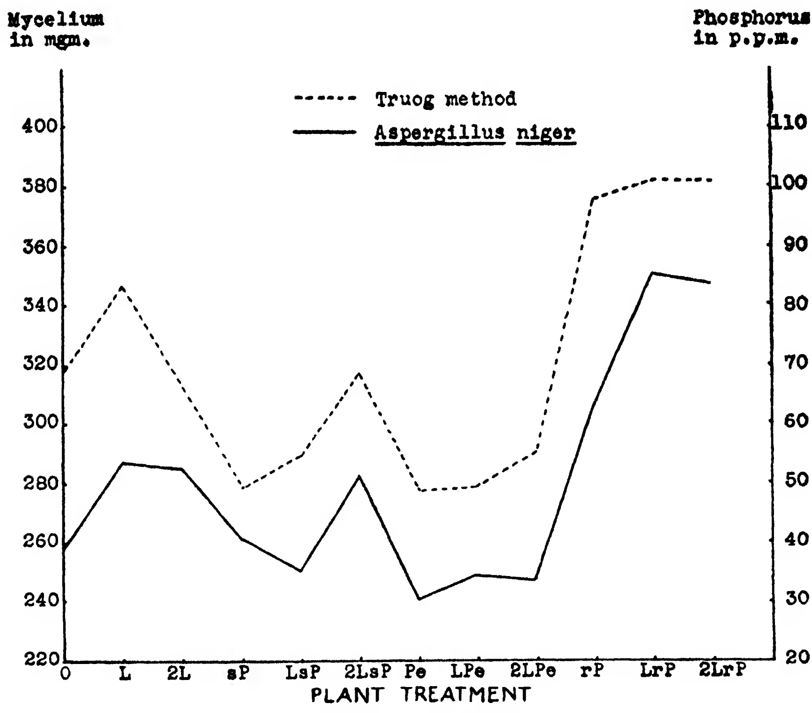

FIG. 2.—Available phosphorus at 12 weeks by different methods.

phosphate there was more effect than with the soil receiving the phosphate alone, a gain of 115.5 mgm in the weight of mycelial growth being shown. There was also a substantial increase in the weight of the mycelial growth when the soil treated with the 6 tons of lime plus 1,000 pounds of rock phosphate was tested over that obtained when the soil receiving rock phosphate alone was used.

At the 12 weeks sampling the weight of mycelial growth produced with the variously treated soils was less than that produced with the samples taken after 6 weeks, except in the case of the soils treated with 3 tons of lime and with 3 tons of lime plus 78 pounds of rock phosphate per acre where there were increases of 15.4 and 12.5 mgm, respectively.

When the check soil was used 257.9 mgm of mycelial growth were produced. With the soil receiving the 3-ton lime treatment there was a stimulation in growth, an increase of 29.9 mgm being obtained; whereas, with the soil receiving the 6 tons of lime per acre, there was an increase of 27.7 mgm in the weight of mycelial growth. When the soil treated with superphosphate alone was used, there was an increase of 3.6 mgm of mycelial growth over that obtained with the untreated soil. With the soil receiving 3 tons of lime per acre plus the superphosphate, that treated with the 78 pounds of rock phosphate per acre alone, and the soils receiving 3 or 6 tons of lime with 78 pounds of rock phosphate, there was less growth than with the corresponding check soils. When the soil treated with 1,000 pounds of rock phosphate per acre was tested there was an increase of 49.3 mgm of mycelial growth over the weight obtained when the check soil was used. With the soil receiving 1,000 pounds per acre of rock phosphate plus 3 tons of lime per acre there was an increase of 62.7 mgm of mycelial growth and with the soil treated with 6 tons of lime there was an increase of 61.0 mgm of mycelial growth over the weight obtained respectively with the soils receiving the 3 tons and 6 tons of limestone. With those soils receiving the lime with the rock phosphate, there were increases in mycelial growth of 43.3 mgm and 39.4 mgm, respectively, for the 3- and 6-ton amounts of lime over the mycelial growth secured with the soil treated with the rock phosphate alone.

RESULTS WITH THE TRUOG METHOD

The Tama silt loam used in the experiment was found to contain 35.0 p.p.m. of available phosphorus by the Truog method when the experiment was started in the greenhouse. Six weeks later the untreated soil contained 36.4 p.p.m. of available phosphorus. The application of 3 tons of lime per acre increased the availability of the soil phosphorus 2.6 p.p.m. Six tons of lime per acre brought about a still greater increase, 55.5 p.p.m. of available phosphorus being extracted or an increase of 19.1 p.p.m. over that in the check soil.

Superphosphate applied alone to the soil increased the available phosphorus 3.3 p.p.m. With superphosphate and 3 tons of lime per acre, the available phosphorus was increased 6.5 p.p.m. over the amount available in the soil receiving the 3 tons of lime per acre alone. With 6 tons of lime per acre along with the superphosphate there was a slight, though apparently insignificant, decrease in the amount of available phosphorus over that present in the soil receiving superphosphate alone.

The application of 78 pounds of rock phosphate per acre to the acid Tama silt loam apparently had little influence on the amount of available phosphorus in the soil. However, when 3 tons of lime were applied with the rock phosphate, the amount of available phosphorus

TABLE 2.—*Available phosphorus in the Tama silt loam by the Truog method.*

Treatment	P.p.m.	
	After 6 weeks	After 12 weeks
Check	36.4	69.1
3 tons lime per acre	39.0	83.4
6 tons lime per acre	55.7	66.1
120 lbs. 20% superphosphate per acre	39.7	49.3
3 tons lime+120 lbs. 20% superphosphate per acre	45.5	54.9
6 tons lime+120 lbs. 20% superphosphate per acre	54.2	68.7
78 lbs. 300-mesh rock phosphate per acre	36.0	49.0
3 tons lime+78 lbs. 300-mesh rock phosphate per acre	52.0	49.8
6 tons lime+78 lbs. 300-mesh rock phosphate per acre	63.5	55.2
1,000 lbs. 300-mesh rock phosphate per acre	91.4	98.0
3 tons lime+1,000 lbs. 300-mesh rock phosphate per acre	101.4	101.0
6 tons lime+1,000 lbs. 300-mesh rock phosphate per acre	100.8	100.8

was increased to such an extent that approximately 100% of the P_2O_5 applied in the 78 pounds of rock phosphate was recovered after 6 weeks. There was an increase in available phosphorus of 16.0 p.p.m. due to the lime. With the 6 tons of lime per acre plus the rock phosphate the amount of available phosphorus extracted was still greater, 11.5 p.p.m. more available phosphorus being obtained than when the 3 tons of lime were used with the phosphate.

When rock phosphate was applied at the rate of 1,000 pounds per acre there was an increase in available phosphorus of 55.0 p.p.m. When 3 tons of lime per acre were applied with the phosphate the increase was slightly greater, being 65.0 p.p.m., but when 6 tons of lime per acre were used no further gain was noted. The application of lime was apparently quite effective in stimulating the production of available phosphorus from the rock phosphate.

After 12 weeks in the greenhouse the check soil and the soils treated with 3 or 6 tons of lime per acre all showed a marked increase in available phosphorus over that present after 6 weeks, the greatest effect appearing with the 3-ton application.

In general, it appears that after 12 weeks there was a definite increase in the amount of available phosphorus present in the soils over that found at the end of the 6 weeks period. Only when the 78 pounds of rock phosphate per acre were applied with either the 3 tons or the 6 tons of lime per acre was there a decrease.

At this sampling the 3-ton application of lime alone increased the

availability of phosphorus, but the 6-ton application gave no increase. With the superphosphate alone or applied with 3 or 6 tons of lime per acre there was no increase in available phosphorus over that in the check soil. With the application of the 78 pounds of rock phosphate alone or with either amount of lime there was likewise no increase in available phosphorus over that in the check soil.

With the 1,000 pounds of rock phosphate per acre alone or applied with lime, large increases in readily available phosphorus were shown over the amounts present in the check soils or in the soils treated with lime alone. However, the increases were not so great as those shown after the first 6 weeks; neither were the effects of the lime so evident, although lime with the rock phosphate again increased the amount of available phosphorus in the soil.

DISCUSSION AND SUMMARY

When the results secured by the Niklas, Poschenrieder, and Trischler method and by the Truog method for measuring available phosphorus are compared in Figs. 1 and 2, it will be seen that the curves are very nearly parallel and the growth of *A niger* as indicated by the weight of mycelial growth is apparently, therefore, directly correlated with the available phosphorus in the soil. It should be noted further that the *A. niger* nutrient medium contained 1.0% citric acid, giving the medium a reaction of pH 4.05. This citric acid was probably mainly responsible for making the phosphorus in the soil available for the growth of the mold In fact it may be assumed that *A. niger* obtained no more phosphorus from the soil than that which was extracted by the citric acid. Hence, it appears that the amounts of phosphorus soluble in 0.002 N sulfuric acid and in 1.0% citric acid are relatively similar and both methods probably indicate the amounts of available phosphorus in the soil.

When the results for the 6 weeks and the 12 weeks periods are compared, as shown in Figs. 1 and 2, it appears that at 12 weeks the relative amount of available phosphorus was greater than at 6 weeks, while the weight of the *A. niger* mycelial growth was slightly less at 12 weeks than at 6 weeks. Without further tests it would be quite impossible to give definite reasons for this. Possibly the difference was due to the age of the mold spores used in the preparation of the inoculating culture, which in both cases was 4 days. If, for any reason, the spores did not germinate as rapidly in one culture as in the other, there would undoubtedly be a great variation in the number of spores in the suspension used for the inoculation and this difference would probably affect the growth of mycelium.

It will be noted from the data in Tables 1 and 2 that after 12 weeks the availability of the phosphorus in the soils receiving superphosphate or the equivalent application of rock phosphate, with or without lime, was not increased over that in the check soils nor were the increases as great in the soils treated with lime and the phosphates as with lime alone. Apparently, the phosphates stimulated biological action in the soil, and hence a part of the available phosphorus was utilized and was not extracted with 0.002 N sulfuric acid or 1.0% citric acid. Phosphorus absorption by the soil was also undoubtedly an important factor along with nitrification in reducing the availability of the phosphorus in the treated soils compared with that in the corresponding check soils.

With the 1,000-pound applications of rock phosphate per acre, however, there were large increases in available phosphorus present, as might be expected. The applications of lime with the rock phosphate increased the availability of the phosphorus, the 3 tons of lime having as great an effect as the larger application The influence of the lime was more definitely shown by the growth of *A. niger* than by the extraction of available phosphorus by the 0.002 N sulfuric acid.

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A STUDY OF THE NEUBAUER AND WINOGRADSKY (AZOTOBACTER) METHODS AS COMPARED WITH A CHEMICAL METHOD FOR THE DETERMINATION OF PHOSPHATE DEFICIENCY IN WESTERN SOILS[1]

H. W. Dahlberg and R. J. Brown[2]

In connection with the sugar beet industry in the states of Colorado Wyoming, Montana, and Nebraska, it has been necessary to develop quick and accurate methods for determining phosphate deficiency in the soils of the irrigated sections of these four states. During the past 4 years we have tried out most of the proposed methods and have tested 300 soil samples by the Neubauer method and over 10,000 samples by the Winogradsky method (Azotobacter). The Neubauer method has been used very extensively in Germany and with the possible exception of the Mitscherlich method is considered the most reliable as a substitute for field trials. Niklas[3] in Europe and Sackett[4] in this country have done much valuable work on the Winogradsky method, but data on actual comparisons between the two methods are extremely meager. As our experience with the Neubauer and Winogradsky methods has probably been more extensive than in the case of any other work done in the United States, both as to number and variety of soils gathered from very large areas, the results obtained should be of interest to soil investigators.

SOILS AND PROCEDURE

The soils tested from the four states mentioned range in pH from 7.1 to 9.1 and include sandy, sandy loam, and very heavy clay soils. Total nitrogen content averages 0.10% and the nitrate content (NO_3) ranges from 30 to 450 p.p.m. Practically all soils are rich in available potash, ranging from 30 to 80 mgm K_2O per 100 grams by the Neubauer method. The majority of them are rather deficient in P_2O_5, 70% falling in the classification of "very deficient" by both the Neubauer and Winogradsky methods.

The Neubauer method was the first to be used on a considerable

[1]Contribution from the research laboratory of the Great Western Sugar Company, Denver, Colorado. Also presented at the annual meeting of the Society held in Chicago, Ill., November 20, 1931. Received for publication November 20, 1931.

[2]Research Manager and Research Chemist, respectively.

[3]Niklas, H., Scharrer, K., and Strobel, A. Phosphatlöslichkeit und Azatobakterwachstum. Landw. Jahrb., 63: 387–410. 1926.

[4]Sackett, W. G. Determining soil deficiencies. Amer. Fert., 73: No. 3, 36. 1930.

scale. As pointed out by Thornton,[5] this is a method which requires great care and attention to detail, both in growing the rye sprouts and in making the chemical determinations on the ashed material. It is not only highly important that the rye kernels selected be plump and uniform in weight, but we also strongly recommend that they be germinated between blotting paper before planting, so that one may obtain about 96 plants for each 100 kernels planted. An excellent description of the Neubauer method is given in a pamphlet entitled "Determination of the Plant Food Content of the Soil," which may be secured from the National Seed Company, 120 Broadway, New York, and we shall therefore not go into further details regarding the method.

After having found the Neubauer method accurate and reliable for our soils by field trials, we used it to standardize the Winogradsky method. This was necessary because the former method is such a time-consuming one that it would have been physically impossible to test 5,000 soils annually, as we are doing, by the latter method. The following basis was used for the classification of our soils:

Neubauer value—0 to 5.0 mgm P_2O_5 (very deficient) = Class C
Neubauer value—5.1 to 8.0 mgm P_2O_5 (possibly deficient) = Class B
Neubauer value—8.1 mgm and above (no deficiency) = Class A

This classification was adopted 2 to 3 years ago and has proved very satisfactory in comparison with field trials. During the past year we made a further effort to develop a still more rapid method of determining phosphate deficiency. In connection with its development we decided to make a very careful comparison of three methods, *viz.*, Neubauer, Winogradsky, and the new method employing extraction of the soil by a sodium acetate buffer of 5.0 pH, on 101 soils. The results by the three methods will be given first, and later the new chemical method will be described. In order that the three methods might be compared entirely impartially, the work on each method was done largely by different men. It is somewhat regrettable that a larger percentage of the soils chosen did not fall in Groups A and B, but the results are typical for the soils of the four states in question. In Table 1, the Neubauer value is given both in terms of the group classification (A, B, C) and in terms of actual Neubauer values.

DISCUSSION OF RESULTS

The results are shown graphically in Fig. 1. The Neubauer values on the various soils are represented by the solid line. The boundaries

[5]THORNTON, S. F. Experiences with the Neubauer method for determining mineral nutrient deficiencies in soils. Jour. Amer. Soc. Agron., 23: 195. 1931.

TABLE 1.—*Comparison of P_2O_5 values of soils by various methods with the Neubauer value taken as standard.*

Sample No.	District	P_2O_5 grade			
		Neubauer		Winogradsky	Chemical
3471	Wheatland, Wyo.	C	3.5 mgm.	C	C
3472	Wheatland, Wyo.	C	1.7 mgm.	C	C
3473	Wheatland, Wyo.	C	0.8 mgm.	C	C
3474	Wheatland, Wyo.	C	4.2 mgm.	C	B
3475	Wheatland, Wyo.	C	3.5 mgm.	C	C
3476	Wheatland, Wyo.	C	1.8 mgm.	C	C
3477	Wheatland, Wyo.	C	3.4 mgm.	C	C
3478	Wellington, Colo.	C	1.5 mgm.	C	C
3544	Lovell, Wyo.	C	0.0 mgm.	C	C
3545	Lovell, Wyo.	C	1.7 mgm.	C	C
3546	Lovell, Wyo.	C	0.5 mgm.	C	C
3547	Lovell, Wyo.	C	4.9 mgm.	C	C
3548	Lovell, Wyo.	C	2.5 mgm.	C	C
3549	Lovell, Wyo.	C	2.1 mgm.	C	C
3550	Lovell, Wyo.	C	1.4 mgm.	C	C
3551	Lovell, Wyo.	C	1.2 mgm.	C	C
3552	Lovell, Wyo.	C	3.2 mgm.	C	C
3553	Lovell, Wyo.	C	1.3 mgm.	C	C
3554	Lovell, Wyo.	C	2.3 mgm.	C	C
3555	Lovell, Wyo.	C	1.6 mgm.	C	C
3556	Lovell, Wyo.	C	3.3 mgm.	C	C
3557	Lovell, Wyo.	C	2.7 mgm.	C	C
3558	Lovell, Wyo.	C	4.2 mgm.	C	C
3559	Lovell, Wyo.	C	1.4 mgm.	C	C
3560	Lovell, Wyo.	C	2.4 mgm.	C	C
3561	Lovell, Wyo.	C	1.0 mgm.	C	C
3562	Lovell, Wyo.	C	0.5 mgm.	C	C
3563	Lovell, Wyo.	C	3.4 mgm.	C	C
3566	Lovell, Wyo.	C	0.4 mgm.	C	C
3567	Lovell, Wyo.	C	4.1 mgm.	C	B
3568	Lovell, Wyo.	C	2.4 mgm.	C	C
3569	Lovell, Wyo.	C	3.8 mgm.	C	A
3570	Lovell, Wyo.	C	4.0 mgm.	C	A
3571	Lovell, Wyo.	C	3.6 mgm.	C	C
3572	Lovell, Wyo.	C	3.0 mgm.	C	B
3573	Lovell, Wyo.	C	2.2 mgm.	C	C
3574	Lovell, Wyo.	C	1.5 mgm.	C	C
3575	Lovell, Wyo.	C	3.9 mgm.	C	C
3576	Lovell, Wyo.	C	1.3 mgm.	C	C
3577	Lovell, Wyo.	C	3.7 mgm.	C	C
3586	Lovell, Wyo.	C	4.0 mgm.	C	A
3587	Lovell, Wyo.	C	2.9 mgm.	C	C
3588	Lovell, Wyo.	C	2.0 mgm.	C	C
3589	Lovell, Wyo.	C	2.2 mgm.	C	C
3590	Lovell, Wyo.	C	2.1 mgm.	C	B
3591	Lovell, Wyo.	C	2.0 mgm.	C	C
3593	Brush, Colo.	C	4.0 mgm.	C	C
3595	Brush, Colo.	C	1.1 mgm.	C	C
3596	Brush, Colo.	C	4.0 mgm.	C	C
3597	Brush, Colo.	C	4.2 mgm.	B	C
3598	Brush, Colo.	C	2.3 mgm.	C	C
3599	Brush, Colo.	C	3.3 mgm.	C	C
3600	Brush, Colo.	C	4.0 mgm.	C	C
3601	Brush, Colo.	C	2.1 mgm.	C	C
3603	Brush, Colo.	C	4.4 mgm.	C	C
3606	Brush, Colo.	C	2.6 mgm.	C	C

TABLE 1.—*Concluded.*

Sample No.	District	P_2O_5 grade			
		Neubauer		Winogradsky	Chemical
3608	Brush, Colo.	C	4.8 mgm.	C	B
3611	Brush, Colo.	C	1.6 mgm.	C	C
3612	Brush, Colo.	C	1.8 mgm.	C	C
3614	Gering, Neb.	C	1.6 mgm.	C	C
3615	Gering, Neb.	C	1.9 mgm.	C	C
3616	Brush, Colo.	C	2.0 mgm.	C	B
3617	Brush, Colo.	C	2.6 mgm.	C	C
3618	Brush, Colo.	C	0.9 mgm.	C	C
3622	Brush, Colo.	C	0.9 mgm.	C	C
3623	Brush, Colo.	C	1.8 mgm.	C	C
3626	Brush, Colo.	C	1.8 mgm.	C	C
3628	Brush, Colo.	C	1.8 mgm.	C	C
3629	Brush, Colo.	C	3.8 mgm.	C	C
3630	Brush, Colo.	C	2.4 mgm.	C	C
3631	Brush, Colo.	C	0.0 mgm.	C	C
3632	Brush, Colo.	C	1.4 mgm.	C	C
3633	Brush, Colo.	C	4.5 mgm.	A	B
3634	Brush, Colo.	C	2.0 mgm.	C	C
3635	Brush, Colo.	C	3.8 mgm.	C	C
3637	Brush, Colo.	C	1.5 mgm.	C	C
3638	Brush, Colo.	C	4.5 mgm.	C	B
3639	Brush, Colo.	C	2.3 mgm.	C	C
3641	Brush, Colo.	C	1.6 mgm.	C	C
3643	Brush, Colo.	C	4.4 mgm.	C	C
3565	Lovell, Wyo.	B	6.2 mgm.	B	B
3592	Brush, Colo.	B	6.1 mgm.	C	A
3594	Brush, Colo.	B	6.5 mgm.	B	B
3602	Brush, Colo.	B	5 6 mgm.	C	B
3604-05	Brush, Colo.	B	7.0 mgm.	C	B
3607	Brush, Colo.	B	7.1 mgm.	C	A
3610	Brush, Colo.	B	6.8 mgm.	B	A
3613	Brush, Colo.	B	6.2 mgm.	A	C
3619	Brush, Colo.	B	6.1 mgm.	B	B
3620	Brush, Colo.	B	6.7 mgm.	B	A
3624	Brush, Colo.	B	6.2 mgm.	C	C
3625	Brush, Colo.	B	5.4 mgm.	C	B
3627	Brush, Colo.	B	5.9 mgm.	C	A
3640	Brush, Colo.	B	5.9 mgm.	C	C
3642	Brush, Colo.	B	5.3 mgm.	C	B
3512	Longmont, Colo.	A	9.5 mgm.	B	A
3520	Longmont, Colo.	A	13.0 mgm.	B	A
3523	Windsor, Colo.	A	9.2 mgm.	C	B
3609	Brush, Colo.	A	8.8 mgm.	C	A
3621	Brush, Colo.	A	11.0 mgm.	B	A
3636	Brush, Colo.	A	10.1 mgm.	A	A

of the three groups, as regards available P_2O_5 content, are shown in heavy lines at 5.0 and 8.0 mgm. Since the classification by the Winogradsky and the chemical methods is only by groups, the breaks in the lines representing the results by these methods are necessarily very abrupt.

Results of 101 tests are tabulated of which 73 show the same result by the three methods. The results of the Neubauer and Winogradsky

tests are in agreement in 83 cases. The Neubauer and chemical tests are in agreement in 82 instances and 75 of the Winogradsky and chemical tests agree. The poorer agreement between the results of the Winogradsky and chemical tests is caused by a tendency of the Winogradsky to yield low results in soils of high available P_2O_5 content, while the chemical method tends to show some high results in soils of low P_2O_5 content. Since the three classifications of soils according to available P_2O_5 content are not equally represented in the samples tested, a better picture of comparisons is obtained by comparing the soils according to groups.

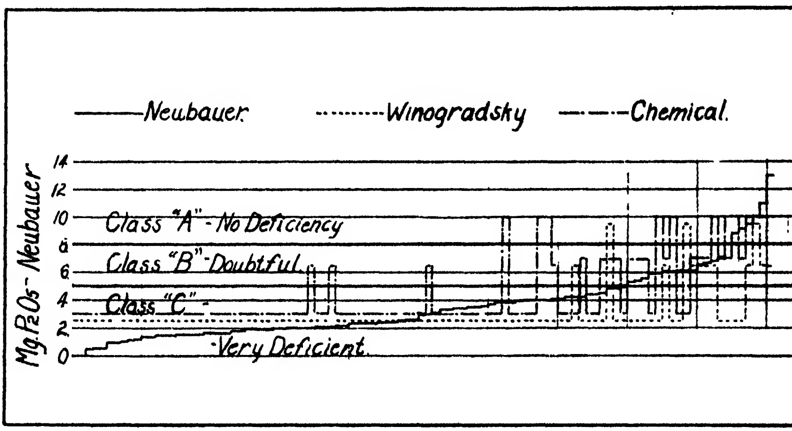

FIG. 1.—Plant-available P_2O_5 in 101 soils as shown by three methods.

In the deficient group (C), 68 of the 80 agree by all three methods; 78 of the 80 agree by the Neubauer and Winogradsky methods; 69 out of the 80 agree by the Neubauer and chemical tests; and 68 of the 80 agree by the Winogradsky and chemical tests.

In the questionable group (B), 4 of the 15 soils agree by all three tests; 5 of the 15 agree by the Neubauer and Winogradsky tests; 8 of the 15 agree by the Neubauer and chemical tests; and 6 of the 15 agree by Winogradsky and chemical tests

In the non-deficient group (A), 1 of the 6 samples shows agreement by all methods. The Neubauer and Winogradsky tests agree in 1 of the 6 tests; the Neubauer and chemical tests agree in 5 of the 6 tests; and the Winogradsky and chemical tests show agreement in 1 of the 6 cases.

If the Neubauer test is accepted as standard, we find the Winogradsky method a highly satisfactory substitute on deficient soils, but not on soils of higher P_2O_5 content. On the other hand, the chemical method agrees with the Neubauer method on 85% of the deficient

and non-deficient soils and on above 50% of the questionable soils. Due to the rather narrow range of the questionable group and to the possible error of the blank in the Neubauer test, a high percentage agreement can hardly be expected in this class.

To establish the relative accuracy of the three tests an extensive course of parallel tests in which the results are compared with those of field trials would be required. While comparison with field trials has shown both the Neubauer and Winogradsky tests to yield satisfactory results, perfect agreement is not obtained, and in the absence of parallel tests by all methods, including field trials, the exact significance of disagreement in results of the three tests cannot be known.

On the basis of results of field trials compared to both Neubauer and Winogradsky tests, we can say positively that of all soils graded in class "C" by either of these two methods, 50% are so deficient in available phosphoric acid that when sugar beets are grown on them they will suffer from the disease known as "black heart" caused from phosphate starvation. The sugar beet suffers to a greater extent than most crops from this malnutrition, and we have repeatedly cured this disease by spreading superphosphate between the beet rows, even as late as July and August. It may be mentioned in passing that the same soil which develops this disease in sugar beets will grow very satisfactory grain crops, although grain gives a decided response to phosphate fertilization. We can say further with regard to the remaining Class "C" soils which do not produce the "black heart" disease that the majority of them will produce from 1 to 2 tons more beets per acre in field trials when 125 pounds of treble superphosphate are applied.

On the basis of our knowledge to date, it appears that the chemical method is a very satisfactory substitute for the time-consuming Neubauer test on soils of the type investigated, and it possibly at least equals the Winogradsky test in accuracy. Since other chemical methods have been found unsatisfactory when applied to these soils, it appears possible that the acetate extration method may not yield satisfactory results on other soils. Therefore, its use is not to be recommended on those soils in the absence of comparative results by other satisfactory methods.

The chemical method, results of which are given in the last column of Table 1, was developed in our research laboratories after exhaustive studies of existing chemical methods, most of which fail when used on western irrigated soils. The new feature of this method consists of the method for obtaining the test solution, the old feature being the use of the Dénigès color determination. Before selecting

the sodium acetate buffer solution of a definite pH, the following methods of obtaining test solutions were tried out: Illinois method (Ill. Agr. Exp. Sta. Bul. 337), water extract of soil, citrate buffer at 6 pH (very dilute), ammonium acetate buffer at 6 pH (very dilute), propionic acid buffer, 1% citric acid solution, boric acid solution, and the Truog method.

None of the above methods gave very satisfactory results. The citrate buffer (1 volume standard buffer to 19 volumes distilled water) came nearest to the results obtained with the acetate buffer finally adopted. Any of the methods using solutions of low pH gave entirely too high figures for available P_2O_5.

SODIUM ACETATE BUFFER METHOD

The method is a modification of the Illinois method, in which the soil is extracted with 0.25 N, 5 pH sodium acetate buffer solution, rather than with the acid molybdate reagent, and color is developed in a solution of the same hydrochloric acid and ammonium molybdate concentration, by means of a tin rod, as is employed in the Illinois method.

Since all of the soils tested contain relatively large quantities of acid-soluble P_2O_5, irrespective of the quantity of plant-available P_2O_5, it was deemed advisable to attempt to find a solution which would have a solvent action approximating that of the weak plant root acid secretions. Accordingly, the actions of buffer solutions were determined. The P_2O_5 content of the extract was determined by addition of an acid ammonium molybdate solution followed by reduction with tin. Since high buffer concentrations prevent the formation of the blue color during reduction of the acid molybdate solution, the maximum buffer concentration permissible is limited by this factor.

Of the various solvents investigated, the sodium acetate buffer at 5 pH, 0.25 N with respect to NaOH, yielded the best results as regards comparison with other satisfactory methods for determination of plant-available P_2O_5. The requirements are that the proper quantity of P_2O_5 be brought in solution and that the solvent does not interfere with the formation of the blue color.

The test was standardized by trial on soils of various known plant-available P_2O_5 contents. Solutions of chemicals were prepared which approximately matched, in tint and intensity, the blue of the phosphate test. Two of these solutions of colors on the dividing line between those produced by deficient and questionable soils and between

those produced by questionable soils and those containing a sufficiency of P_2O_5 were selected as standards.

The color standards were prepared from solutions of $CuSO_4$, $Co(NO_3)_2$, and $NiCl_2$. The colors appear to remain permanent indefinitely. Work on preparation of standards has shown that the matching of colors must be done under standard conditions, apparently due to the fact that the standards are true solutions, while the molybdenum blue is a colloidal solution in which the intensity of color does not vary directly with depth of layer. Standard conditions are given in the detailed method below.

After standardization the method was employed on the 101 soils listed in Table 1. The advantages of the method are its accuracy, simplicity and speed, and the reproducibility of results. Its disadvantages are readiness with which the blue solution is discolored by excessive reduction and the fading of the color on standing. Conformity to the details of manipulation prevent errors from these sources.

DESCRIPTION OF SODIUM ACETATE BUFFER METHOD

REAGENTS

Sodium acetate buffer —Dissolve 10.0 grams NaOH in distilled water, add acetic acid to produce 5 0 pH (about 19 ml of glacial acetic acid), and make to 1 liter.

Molybdate stock solution —Dissolve 100 grams of highest purity ammonium molybdate, phosphate free, in 850 cc of distilled water. Filter the solution and cool it. Then add it slowly with constant stirring, to a cold mixture of 1,700 cc of concentrated HCl (36%) and 700 cc of water

Molybdate reagent.—Dilute 24 cc of the molybdate stock solution to 100 cc with distilled water.

Tin rod —A rod 7 to 8 inches long, smooth in order that it may be cleaned and dried easily, and flattened at one end to facilitate stirring contents of test tube.

COLOR STANDARDS

1. Introduce into a 6 x 5/8 inch test tube 7.5 cc of $CuSO_4$ solution (No. 3 below), 2.0 cc of $NiCl_2$ solution (No. 4 below), and 1.6 cc. of $Co(NO_3)_2$ solution (No. 5 below) and mix.

2. Introduce into a 6 x 5/8 inch test tube 2.2 cc of $CuSO_4$ solution (No. 3 below), 1.9 cc of $NiCl_2$ solution (No. 4 below), and 1.1 cc of $Co(NO_3)_2$ solution (No. 5 below), and add about 5 cc of water and mix.

SOLUTIONS FOR PREPARATION OF COLOR STANDARDS

3. Dissolve 30 grams of $CuSO_4.5\ H_2O$ in water and make to 100 cc.

4. Dissolve 5 grams of $NiCl_2.6\ H_2O$ in water and make to 100 cc.

5. Dissolve 5 grams of $Co(NO_3)_2.6\ H_2O$ in water and make to 100 cc.

The test tubes containing the color standards are placed in a suitable holder which will permit observation vertically through the length of the column of liquid. Provision must be made for observing the solution under test in comparison with the standards.

PROCEDURE

Mix 5 grams of the soil under examination with 25 cc of the acetate buffer, shaking occasionally during a period of 5 to 10 minutes. Filter the mixture, being careful to obtain a sparkling filtrate. Place 5 cc of the soil extract in a 6 x 5/8 inch test tube, add 5 cc of molybdate reagent, and mix. Clean and dry the tin rod, insert into test tube, permitting it to touch bottom, and rotate for 1 to 5 seconds. Remove tin rod immediately, mix contents of tube, and compare with color standards Nos. 1 and 2 immediately.

If intensity of color is greater than that of No. 1 standard, P_2O_5 in soil is in excess. If intensity of color is less than that of No. 2 standard, P_2O_5 in soil is deficient. Intensity of color between these two values places the soil in the doubtful group.

PRECAUTIONS

Blank tests on reagents should not produce more than a very faint greenish coloration. Tin rod should always be dry before inserting into solution. Removal of rod from solution followed by reinsertion of wet rod often produces discoloration.

The tin should be in contact with the solution only for that period of time required to develop the maximum color. The time required varies from 1 second or less on extracts of low P_2O_5 content to 3 to 5 seconds on extracts high in P_2O_5. Employment of the tin rod for a time appreciably longer than necessary causes discoloration of the solution. The extent of change in color following immediately after the introduction of the tin rod into the solution is sufficient guide for determining the period of contact required.

If colors develop slowly, the reagents are at fault and should be discarded. Since the blue color produced in the solution is not permanent, it should be compared with the standards immediately after development.

THE INFLUENCE OF LIME AND PHOSPHATE FERTILIZERS ON SOIL REACTION[1]

F. B. Smith, P. E. Brown, J. B. Peterson, and F. E. Schlots[2]

Recently it has been stated that rock phosphate functions in reducing the lime needs of acid soils, but no definite information is available on the subject. The work reported here was begun to secure data on the value of phosphate fertilizers in supplying the calcium requirements of crops grown on acid soils and in neutralizing soil acidity, and this paper presents preliminary results obtained in the study. While no definite conclusions can be drawn, it is believed that a progress report may stimulate interest in the subject.

EXPERIMENTAL

EFFECT OF LIME AND PHOSPHATE FERTILIZERS ON REACTION OF TAMA SILT LOAM IN THE GREENHOUSE

Tama silt loam which had a lime requirement of 3 tons per acre by the Truog method was selected for this study. The soil was pulverized and passed through a ¼-inch sieve. The soils were treated in 4-gallon pots in duplicate, the treatments consisting of calcium hydroxide equivalent to 3 tons of limestone or to 6 tons of limestone per acre, 120 pounds of 20% superphosphate per acre, 78 pounds of rock phosphate per acre, and 1,000 pounds of rock phosphate per acre. Two pots of soil were untreated and served as checks. The phosphate fertilizers were also applied in combination with calcium hydroxide equivalent to 3 or 6 tons of lime per acre. The moisture content of the soils was adjusted to 24% by additions of distilled water and maintained at 22 to 24% throughout the experiment.

The soils were sampled at the beginning of the experiment and after 6, 12, and 25 weeks and pH determinations were made by the quinhydrone electrode method. The results secured are presented in Table 1 and are the averages of quadruplicate determinations.

When the experiment was begun the lime requirement of the soil was 3 tons per acre by the Truog method and the pH was 5.87.

The acidity of the untreated soil increased to pH 5.57 after 6 weeks and at the same time in the soil receiving 3 tons of lime per acre the pH was 6.74. If this change in reaction is significant then it would seem that the moisture content of the soil probably influenced the

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results of the Truog test and the pH determination by the quinhydrone electrode method. The soil was very dry when the original test for acidity was made and it was at approximately the optimum moisture content when the tests were made after 6 weeks. With 6 tons of lime the pH was increased to 7.55 at the end of 6 weeks.

TABLE 1.—*Effect of lime and phosphate fertilizers on the reaction of Tama silt loam in the greenhouse.*

Treatment per acre	pH at			
	Beginning	6 weeks	12 weeks	25 weeks
Check	5.87	5.57	5.20	5.46
3 tons lime	5.87	6.74	6.73	6.50
6 tons lime	5.87	7.55	7.54	7.51
120 lbs. 20% superphosphate	5.87	5.54	5.49	5.52
3 tons lime+120 lbs superphosphate	5.87	6.68	6.78	6.55
6 tons lime+120 lbs. superphosphate	5.87	7.57	7.49	7.55
78 lbs. rock phosphate	5.87	5.61	5.43	5.43
3 tons lime+78 lbs rock phosphate	5.87	6.81	6.41	6.44
6 tons lime+78 lbs rock phosphate	5.87	7.57	7.26	7.41
1,000 lbs. rock phosphate	5.87	5.51	5.56	5.47
3 tons lime+1,000 lbs. rock phosphate	5.87	6.85	6.35	6.46
6 tons lime+1,000 lbs. rock phosphate	5.87	7.67	7.31	7.26

The addition of superphosphate alone did not influence the reaction of the soil after 6 weeks. The application of 3 tons of lime per acre with the superphosphate had practically the same effect on the reaction as did the 3 tons of lime alone.

The application of 78 pounds of rock phosphate had no effect on the reaction of the soil after 6 weeks. When applied with 3 tons or 6 tons of lime per acre there was the same effect on the reaction as was brought about by the 3 or 6 tons of lime alone.

Rock phosphate applied alone at the rate of 1,000 pounds per acre had no appreciable effect on the reaction of the soil after 6 weeks. When applied with 3 tons of lime per acre there was a pH of 6.85 in the soil. This was slightly greater than the pH in the soil receiving the lime alone (6.74), but the difference is not significant. Similarly, when the rock phosphate was used with 6 tons of lime per acre, there was a pH of 7.67 in the soil receiving the lime alone. Again the difference could not be considered significant.

After 12 weeks in the greenhouse, the check soil had become still more acid, the acidity increasing from pH 5.57 to 5.20. There was no change in the reaction of the soils receiving the 3 tons and the 6 tons of lime per acre after 12 weeks over that noted after 6 weeks. After 12 weeks the acidity of the soil treated with 120 pounds of

superphosphate per acre was practically the same as at the 6 weeks sampling. It may be noted that the pH of this soil after 12 weeks was 5.49, while that of the check soil was 5.20. The superphosphate seemed to prevent the development of acidity in the soil. When the superphosphate was applied with 3 tons of lime per acre, the acidity of the soil decreased very slightly from pH 6.68 after 6 weeks to pH 6.78 after 12 weeks. When the superphosphate was added with 6 tons of lime per acre there was a very slight increase in acidity. In neither of these cases were the changes significant. With these two latter treatments the reaction of the soils was about the same as in those soils receiving the corresponding treatments of lime without the superphosphate.

All the soils treated with 78 pounds of rock phosphate per acre increased markedly in acidity from the 6 to the 12 weeks sampling. The soil treated with the rock phosphate alone did not become as acid as did the check soil, probably because the phosphate had some effect in buffering the soil In the soils treated with 3 tons of lime and the 78 pounds of rock phosphate per acre the acidity increased from pH 6 81 after 6 weeks to pH 6.41 after 12 weeks. With the heavier application of lime with the 78 pounds of rock phosphate there was a similar increase in acidity after 12 weeks With both these latter treatments the acidity was greater than in the soils receiving the lime alone.

With rock phosphate applied at 1,000 pounds per acre there was no increase in acidity after 12 weeks. However, when the rock phosphate was applied with the 3-ton and the 6-ton application of lime, the acidity increased after 12 weeks from pH 6.85 to pH 6.35 and from pH 7.67 to pH 7 31, respectively. In both cases the acidity was greater than where the same amount of lime was used alone.

After 25 weeks the check soil decreased in acidity from pH 5.20 at 12 weeks to pH 5.46. The soil receiving 3 tons of lime per acre increased in acidity from pH 6 73 at 12 weeks to pH 6.50 and that receiving 6 tons of lime showed no change in reaction. The superphosphate treated soils showed the same acidity, while in the soil receiving the 3 tons of lime with the superphosphate there was an increase in acidity from pH 6.78 at 12 weeks to pH 6.55. The reaction of the soil treated with superphosphate and 6 tons of lime remained practically the same.

The reaction of the soils treated with 78 pounds of rock phosphate per acre and with the rock phosphate plus 3 tons of lime per acre remained the same after 25 weeks as after 12 weeks. When the 78 pounds of rock phosphate were applied with 6 tons of lime per acre

there was a very slight decrease in acidity in the soil from pH 7.26 at 12 weeks to pH 7.41.

In the soil treated with 1,000 pounds of rock phosphate per acre alone, the acidity increased very slightly from pH 5.56 after 12 weeks to pH 5.47 after 25 weeks. When the rock phosphate was applied with 3 tons of lime per acre the acidity decreased from pH 6.35 at 12 weeks to pH 6.46. There was no significant difference between the reaction of this soil after 25 weeks and that receiving the 3 tons of lime without the rock phosphate. When the rock phosphate was added with 6 tons of lime per acre, there was little change in the reaction after 25 weeks from that found after 12 weeks. However, this soil was more acid after 25 weeks than was that receiving the 6 tons of lime alone.

EFFECT OF LIME AND PHOSPHATE FERTILIZERS ON REAÇTION OF CARRINGTON LOAM IN THE GREENHOUSE

Virgin Carrington loam was passed through a ¼-inch sieve and treated in duplicate in 4-gallon pots, the treatments being 1,000 pounds of finely ground rock phosphate per acre, 2,000 pounds of rock phosphate, 120 pounds of 20% superphosphate, 240 pounds of 20% superphosphate, and 2,000 pounds of limestone. Two pots were untreated to serve as checks. The limestone used had the following composition:

Insoluble matter	4.26%
Al, Fe, and Mn oxides	3.81%
Moisture	1.64%
Calcium oxide	23.01%
Magnesium oxide	26.74%
Alkalinity	98.50%

The sieve test showed the following:

17.81% retained on the 10-mesh sieve
22.39% retained on the 20-mesh sieve
17.35% retained on the 40-mesh sieve
13.63% retained on the 100-mesh sieve
28.82% passing through the 100-mesh sieve

The moisture content of the soils was adjusted to 25% and maintained at this figure by frequent additions of distilled water. Samples were taken after 2, 3, 4, 5, 6, 15, and 20 weeks for analysis. The reaction was determined in the beginning and at each sampling by the quinhydrone electrode method. The results are the averages of closely agreeing quadruplicates and are presented in Table 2.

The reaction of the untreated soil was pH 5.90 in the beginning of the experiment and varied somewhat from this figure at the various

TABLE 2.—*The effect of lime and phosphate fertilizers on the reaction of Carrington loam in the greenhouse.*

Treatment per acre	pH at								Average pH
	Beginning	2 wks.	3 wks.	4 wks.	5 wks.	6 wks.	15 wks.	20 wks.	
Check	5.90	6.12	5.95	5.90	5.64	6.00	5.75	5.50	5.85
100 lbs. rock phosphate	5.90	6.06	5.96	5.98	5.93	6.00	5.79	5.65	5.91
2,000 lbs. rock phosphate	5.90	6.06	6.10	5.98	5.84	6.00	5.88	5.75	5.94
120 lbs. superphosphate	5.90	5.85	5.66	5.83	5.73	5.85	5.70	5.65	5.77
240 lbs. superphosphate	5.90	5.75	5.79	5.77	5.63	5.83	5.68	5.58	5.74
2,000 lbs. limestone	5.90	6.84	7.07	6.93	6.86	7.10	7.25	7.20	5.90

samplings, the average after 20 weeks being pH 5.85. The reaction of the soils treated with rock phosphate did not fluctuate quite as did that of the untreated soil at the different samplings. The average figures were pH 5.91 for the soil receiving 1,000 pounds of rock phosphate per acre and pH 5.94 for the soil treated with 2,000 pounds of rock phosphate. When the superphosphate was applied at the rate of 120 or 240 pounds per acre the pH of the soil was slightly lower than that of the untreated soil at all but two samplings in the case of the 120-pound application and one sampling with the 240-pound addition. The average pH was 5.77 and 5.84, respectively, for the soil receiving the 100 and 240 pounds of superphosphate for the 20-week period. Limestone applied at the rate of 2,000 pounds per acre was very effective in decreasing the acidity of this soil, the neutral point being reached in 3 weeks. The average pH was 6.90 for the 20-week period.

In general, these data seem to indicate only very slight effects on the reaction of Carrington loam from the application of finely ground rock phosphate or of superphosphate. On the average the differences in pH were hardly significant. At certain samplings some effects were indicated, but the variations in pH in the samples taken from the pots at the different dates should probably be attributed to soil variations rather than to the effects of the treatments.

INFLUENCE OF SOIL TREATMENT ON REACTION OF CARRINGTON LOAM ON THE AGRONOMY FARM UNDER A 5-YEAR ROTATION

In October, the soils were sampled from the clover plats in the 5-year rotation of corn, oats, clover, winter wheat, and alfalfa, the plats having been under treatment for 15 years. The pH was determined by the quinhydrone electrode method. The data are presented in Table 3.

TABLE 3.—*Influence of soil treatment on the reaction of the Carrington loam on the Agronomy Farm, under a 5-year rotation.*

Treatment	pH
Check	5.54
Manure	5.60
Manure+lime	6.51
Manure+lime+rock phosphate	6.65
Manure+lime+superphosphate	6.79
Check	5.48
Crop residues	5.97
Crop residues+lime	6.74
Crop residues+lime+rock phosphate	6.99
Crop residues+lime+superphosphate	6.91
Check	5.95

The acidity of the manured soil was slightly lower than that of the check soil, the pH being 5.60 compared with pH 5.54 for the check The pH of the soil treated with manure, lime, and rock phosphate was somewhat higher than that of the soil receiving manure and lime and the superphosphate-treated soil had a still higher pH. The natural variation in the acidity of the soil on the different plats is not known, but assuming a progressive increase in acidity from the first check to the second, the difference between the pH of each soil would be only about pH 0.012. From these figures, then, it appears that the acidity was decreased in these soils by pH 0.14 with rock phosphate and by pH 0.29 with superphosphate.

Assuming a progressive decrease in acidity between the second and third checks, the difference in pH between the various soils would be 0.115. The rock phosphate with the lime and crop residues decreased the acidity in the soil by pH 0.25, whereas, the superphosphate with the residues and lime brought about a decrease of pH 0 17.

These data would seem to indicate that over a period of years rock phosphate or superphosphate when applied with lime and manure in a 5-year rotation may bring about slight decreases in the lime requirement of Carrington loam.

EFFECT OF LIME AND PHOSPHATE FERTILIZERS ON REACTION OF CARRINGTON LOAM IN A 4-YEAR ROTATION

A field experiment was begun in the spring of 1929 to test the value of lime, finely ground rock phosphate, and superphosphate on Carrington loam under a 4-year rotation of corn, corn, oats, and clover. Sixteen 1/10-acre plats were laid out 28 feet wide and 155½ feet long with a 7-foot border between each treatment. Two finely ground rock phosphates were used. Applications of 1,000, 500, and 250 pounds per acre were made in duplicate, the one being plowed under and the other being disced into the surface soil. Superphosphate was applied at the rate of 120 pounds per acre to the grain

crops in the rotation. A second series of 16 1/20-acre plats were laid out 28 feet wide and 77¾ feet long with a 7-foot border between each treatment. The 1/10-acre plats received limestone to correct the acidity in the amount as shown by the lime requirement by the Truog method. The series of 1/20-acre plats were left unlimed.

The first crop in the rotation was oats. After the oats were harvested, samples of the soil were taken for pH determinations on both the limed and the unlimed series. Samples were again taken from both complete series in 1931. The results of pH determinations are given in Table 4.

TABLE 4.—*Effect of lime and phosphate fertilizers on the reaction of Carrington loam under a 4-year rotation.*

Plat No.	Treatment*	pH July 29, 1929		pH Aug. 25, 1931	
		Limed	Unlimed	Limed	Unlimed
1	Check	6.19	5.73	6.72	6.28
2	1,000 lbs. T. rock phos. plowed	5.74	5.93	6.51	6.24
3	1,000 lbs. T. rock phos. disced	5.77	5.69	6.10	6.25
4	1,000 lbs. R. rock phos. plowed	5.94	5.74	6.58	5.93
5	1,000 lbs. R. rock phos. disced.	6.17	5.36	6.29	5.95
6	120 lbs. 20% superphosphate	6.17	5.69	6.62	6.00
7	500 lbs. T. rock phos. plowed	6.18	5.37	5.52	5.63
8	500 lbs. T. rock phos. disced .	6.52	5.72	6.87	5.98
9	500 lbs. R. rock phos. plowed.	6.31	5.53	7.27	5.87
10	500 lbs. R. rock phos. disced	6.50	5.68	6 78	5.80
11	120 lbs. superphosphate	6.38	5.63	6.58	5.93
12	250 lbs. T. rock phos. plowed	6.31	5.87	6.43	6.10
13	250 lbs. T. rock phos. disced	5 99	5.83	6.21	6.14
14	250 lbs. R. rock phos. plowed	6.14	6.00	6.80	6.35
15	250 lbs. R. rock phos. disced	6.77	5 91	7.05	6.13
16	Check	6.33	5.62	7.17	6.00

*T=Thompson's rock phosphate; R=Ruhm's rock phosphate.

The reaction of the soils of the different plats was not determined before treatment, but the effect of the treatment is shown by a comparison of the pH of the limed and unlimed soils.

In 1929, the lime decreased the acidity of check plat 1 from pH 5.73 to pH 6.19 and that of check plat 16 from pH 5.62 to pH 6.33. Lime and 250 pounds per acre of rock phosphate decreased the acidity from pH 5.91 to pH 6.77 in the soil on plat 15, while lime plus 1,000 pounds per acre of rock phosphate decreased the acidity from pH 5.36 to pH 6.17 in the soil on plat 5. The other data show a considerable variation in reaction from plat to plat.

There was a slight decrease in the acidity of all soils from 1929 to 1931. Lime had decreased the acidity of check plat 1 from pH 6.28 to pH 6.72 and that of check plat 16 from pH 6.00 to pH 7.17. The maximum effect of lime plus rock phosphate or superphosphate in decreasing the acidity of the soil was not greater in any case than that of lime alone on plat 16.

There seems to be no indication that either rock phosphate or superphosphate have been effective in decreasing the acidity of these soils.

DISCUSSION

When there is a deficiency of bases in the soil, the addition of any base which replaces hydrogen in the soil complex should reduce the hydrogen-ion concentration or acidity of the soil. Theoretically, the phosphorus in superphosphate may be precipitated as iron and aluminum phosphate when the superphosphate is added to acid soil and thus a reduction of the hydrogen-ion concentration may occur. When rock phosphate is added to acid soils it may, under the influence of carbon dioxide, produce calcium bicarbonate, which, with the removal of the phosphate by crops, may leave an excess of soluble calcium. This reaction, however, is reversible, but with a large application of rock phosphate and a removal of the phosphorus it has been suggested that there would remain an excess of soluble calcium available for neutralizing the acidity of the soil. That this is not the case or that it takes place only to a slight extent even over a long period of time is shown in these experiments. However, the amount of calcium released from rock phosphate or superphosphate when used in the amounts applied in these experiments would be small and, while never in sufficient quantities to influence the pH of the soil to any large extent, might be sufficient for maximum crops of even heavy feeders on calcium.

SUMMARY AND CONCLUSIONS

The reaction of Tama silt loam was not changed materially by additions of superphosphate or finely ground rock phosphate over a period of 25 weeks under controlled conditions, whereas calcium hydroxide applied on the basis of 3 tons of limestone per acre decreased the acidity from pH 5.46 to 6.50. In greenhouse experiments superphosphate tended to increase the acidity of Carrington loam and rock phosphate had the opposite effect, but the influence was not very pronounced in either case. In one field experiment with these materials on Carrington loam under a 5-year rotation and over a period of 15 years both superphosphate and rock phosphate tended to decrease the acidity but to an insignificant degree. In another field experiment on Carrington loam but of shorter duration there was no apparent influence of rock phosphate or of superphosphate on the reaction of the soil.

Further work is being done to determine the relation of soluble calcium to reaction and the availability of phosphorus in these soils.

RELATION OF ORGANIC MATTER TO ORGANIC CARBON IN THE PEAT SOILS OF NEW YORK[1]

B. D. Wilson and E. V. Staker[2]

The organic matter of soils is often determined quantitatively by multiplying the percentage of organic carbon in the soil by the Van Bemmelen factor 1.724. In using the factor it is assumed that the organic matter of the soil contains 58% of carbon.

A critical study of the methods for the qualitative determination of soil organic matter lead Waksman and Stevens[3] to conclude that the method mentioned in the preceding paragraph is the most reliable of those now available. In a recent paper, Lunt[4] reports that the factor 1.724 is too low to be applicable to the organic horizons of forest soils. They were found to contain less than 58% of organic carbon, and he suggests a conversion factor of 1.86 when the amount of organic matter in such soils is to be computed from the percentage of organic carbon which they contain. He refers to the results of other investigators who found the value 1.724 to be too low to estimate satisfactorily the amount of organic matter of peat soils.

The literature dealing with the methods for the determination of soil organic matter is reviewed in the two papers which are cited and a repetition is unnecessary at this time. It reveals little information regarding the expediency of using the factor 1.724 in calculating the organic matter content of peat soils from the percentage of organic carbon.

At this laboratory a study of the chemical composition of the peat soils of New York is in progress. As a result of the work data are available which will throw some light on whether the conventional factor for converting organic carbon to organic matter is too low to be applied to peat soils. The purpose of the present paper is to report the organic carbon and the organic matter content of a number of peat soils and to record the factor which was obtained for each soil when its content of organic matter was divided by its content of organic carbon.

[1]Contribution from the Department of Agronomy Cornell University, Ithaca, N. Y. Received for publication November 5, 1931.

[2]Assistant Professor and Research Instructor, respectively.

[3]Waksman, S. A., and Stevens, K. R. A critical study of the methods for determining the nature and abundance of soil organic matter. Soil Science, 30: 97–116. 1930.

[4]Lunt, H. A. The carbon-organic matter factor in forest soil. Soil Science, 32: 27–33. 1931.

SOILS OF THE INVESTIGATION

The soils of the report were collected in various sections of New York. All of the samples were taken from virgin peat deposits adjacent to cultivated areas. Most of uncleared soils of these areas are now in hardwood forests. Softwoods occur, but they are less abundant.

As a rule, the surface soils of the cultivated peat sections of New York are woody in character containing fragments of both hardwoods and softwoods. The underlying soil is derived primarily from reeds, but frequently sedge or cat-tail predominates. The surface zone of one of the deposits from which a sample of soil was collected is composed of sphagnum moss.[5] At lower depths the deposit grades into a partly decomposed reed and sedge peat. With this exception, the soils of the investigation are woody peat soils.[6]

Sampling was accomplished by means of a spade after the ground-cover vegetation was removed from the surface of the soil. Surface and subsoil samples were collected from each of 55 stations. Some of the stations were widely separated and others were located within a distance of a few hundred feet.

The surface soils were taken to a depth of 1 foot and the subsoils from 1 to 2 feet About 8 pounds of soil were taken for each sample, which later was air dried and prepared for analysis by grinding all of the soil in a Wiley mill. A portion of the resulting sample was ground in a porcelain mortar until it passed entirely through a sieve having 100 meshes to the linear inch.

METHOD OF ANALYSIS

Loss of weight on ignition was taken as a measure of the organic matter content of the soils. For that purpose 10 grams of soil were weighed into a platinum dish and ignited to constant weight in an electric combustion furnace. The temperature of the furnace was held at approximately 600°C. This method of determining organic matter has a comparatively high degree of accuracy with reference to peat soils because of the small amount of mineral matter which they contain.

The dry combustion method was used for the determination of organic carbon. The standard procedure, using a Bunsen combustion furnace, was followed. Though time consuming, this method was

[5]Soil No. 55, which is listed in Table 1, was collected from a sphagnum moss bog.

[6]The writers are indebted to Dr. A. P. Dachnowski-Stokes of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, for a detailed description of the profiles of the soils used in this investigation. Only a partial description is given in the present paper.

selected because of its accuracy. Methods based on the volumetric measurement of carbon dioxide proved unsatisfactory because of the large volume of gas which resulted from an extremely small quantity of soil.

ORGANIC MATTER AND ORGANIC CARBON

The amounts of organic matter and of organic carbon which were found in each of the soils are shown in Table 1. The factors which were obtained for each of the soils when the percentages of organic matter were divided by the percentages of organic carbon are to be seen in the third and sixth columns of the table.

TABLE 1.—*The organic matter and the organic carbon content of peat soils and the factors obtained by dividing the organic matter content by the organic carbon content.*

Soil No.	Surface soil: Percentage of dry soil: Organic matter by ignition	Surface soil: Percentage of dry soil: Organic carbon	Surface soil: Factor	Subsoil: Percentage of dry soil: Organic matter by ignition	Subsoil: Percentage of dry soil: Organic carbon	Subsoil: Factor
1	85.11	48.77	1 745	83.72	49.88	1.678
2	86.08	49.63	1.734	86.75	50.38	1.721
3	78.16	43.80	1.784	89.07	49.56	1.797
4	86.15	48.69	1.769	83.72	48.63	1.721
5	84.32	49.63	1.699	84.44	50.08	1.686
6	83.40	47.82	1.744	84.97	49.24	1.726
7	83 21	46 87	1 775	82.02	48 96	1.675
8	82.99	45.99	1.804	83.05	47.79	1.738
9	82.76	46.56	1.777	80.16	46.34	1.730
10	84.75	47.42	1.787	85.20	48.46	1.758
11	84.62	46.90	1.804	88.71	47.19	1.880
12	88.46	46.96	1.884	88.73	49.43	1.795
13	85.34	45.29	1.884	80.47	46.63	1.726
14	83.86	46.48	1.804	85.80	48.18	1.781
15	84.10	48.37	1.739	82.72	48.23	1.715
16	79.98	46.14	1.733	82.86	49.14	1.686
17	91.27	53.04	1.721	92.78	59.37	1.563
18	93.43	54.72	1.707	92.52	58.84	1.572
19	81.55	45.54	1.791	83.89	49.01	1.712
20	83.26	46.70	1.783	87.08	51.42	1.693
21	80.92	46.03	1.758	83.86	48.82	1.718
22	82.86	46.83	1.769	84.18	49.68	1.694
23	81.46	44.84	1.817	83.47	48.62	1.717
24	75.11	41.46	1.812	81.73	47.71	1.713
25	79.53	46.41	1.714	84.02	50.19	1.674
26	79.08	44.68	1.770	78.04	43.50	1.794
27	82.26	46.17	1.782	87.21	49.99	1.744
28	84.44	46.82	1.803	88.73	52.16	1.701
29	86.51	49.01	1.765	89.37	54.07	1.653
30	86.90	50.07	1.735	89.07	52.46	1.698
31	80.24	44.26	1.813	87.92	52.14	1.686
32	86.19	50.75	1.698	86.04	51.27	1.678
33	92.22	54.72	1.685	96.36	58.03	1.660
34	95.36	54.14	1.761	97.05	57.11	1.699

TABLE 1.—*Concluded.*

Soil No.	Surface soil: Percentage of dry soil: Organic matter by ignition	Surface soil: Percentage of dry soil: Organic carbon	Surface soil: Factor	Subsoil: Percentage of dry soil: Organic matter by ignition	Subsoil: Percentage of dry soil: Organic carbon	Subsoil: Factor
35	81.02	46.06	1.759	87.87	51.48	1.707
36	85.55	47.50	1.801	88.37	51.86	1.704
37	84.11	49.96	1.683	84.90	51.05	1.663
38	82.98	48.36	1.716	84.86	50.79	1.671
39	94.16	56.49	1.667	94.81	59.76	1.586
40	84.16	49.54	1.699	86.74	50.37	1.722
41	83.35	48.94	1.703	85.49	50.47	1.694
42	83.86	45.45	1.845	86.84	49.42	1.757
43	78.27	45.69	1.713	90.17	53.20	1.695
44	68.24	36.95	1.847	81.34	47.14	1.725
45	86.96	50.72	1.714	92.93	53.97	1.722
46	94.39	55.02	1.715	94.18	55.13	1.708
47	84.33	46.33	1.820	84.73	48.58	1.744
48	84.47	47.16	1.791	87.35	50.44	1.732
49	80.97	45.82	1.767	85.21	50.05	1,702
50	76.53	42.87	1.785	92.48	53.72	1.721
51	84.70	48.18	1.758	83.37	49.08	1.699
52	84.10	47.12	1.785	84.69	49.07	1.726
53	75.76	42.20	1.795	74.33	43.41	1.712
54*	77.74	44.60	1.743	33.77	20.84	1.620
55	94.67	50.37	1.879	94.21	57.35	1.643
Av.	83.93	47.58	1.766±.003	85.53	50.18	1.706±.005

*Soil 54 is underlain with marl at a depth of less than 2 feet which accounts for the relatively small amount of organic matter and of organic carbon which the subsoil contains.

The surface soils were found to contain, on the average, slightly less of both organic matter and organic carbon than the subsoils. This difference probably is due to the deposition from the upland of inorganic material in the surface layer of soil.

Considerable variation is to be noted in the value of the factors recorded. The values of the surface soils vary from 1.884 to 1.667 and those of the subsoils from 1.880 to 1.563. The average factors for the surface soils and the subsoils are 1.766 and 1.706, respectively. In one case the value is larger and in one case it is smaller than the conventional factor 1.724. If the factors for all of the soils are averaged, the value becomes 1.736, which approximates very closely the factor now in general use. In many instances the factor for an individual soil is shown to be higher than the factor 1.86 which is suggested by Lunt for peat soils. On the other hand, many of the values are shown to be much lower than 1.724.

The average factors for the soils of the different peat areas of New York were not found to differ materially from the factor for

the peat soils of the state as a whole. In view of that fact, the data for the individual areas of the state are not presented.

CONCLUSIONS

It is obvious that no factor could be selected that would apply to all of the soils of the present report if more than approximate values of the organic matter which they contain are desired. A factor of 1.86, which is suggested by Lunt as being approximately correct for peat soils, would undoubtedly be too high for the peat soils of New York.

From the results here reported it would seem that 1.724 is as appropriate as any single factor that might be chosen for the purpose of calculating from the percentage of organic carbon the percentage of organic matter in the peat soils of New York. The value 1.736 which is obtained when the factors for the 110 peat soils of the investigation are averaged, indicates that the chemical composition of the organic matter of the soils is similar to that of mineral soils.

AN OUTLINE OF A COURSE IN CROP BREEDING[1]

JOHN B. WENTZ[2]

Most attempts to standardize courses in farm crops have dealt with the introductory course. There are several reasons for this. In the first place it would seem more logical to direct our attentions first to the beginning courses which are common to all the agricultural curricula. The introductory course affects the largest number of students and commands the interest of the largest number of teachers. At the same time, referring more specifically to the content of the courses, it would seem that there might be greater possibilities for standardization in some of the advanced courses than in the more elementary courses. The greatest limiting factor in the standardization of courses in the field of farm crops is the great variation in crops and climatic and soil conditions in different sections of the country. This factor is not so serious in the standardization of most of the more advanced courses.

The following outline is not presented with the idea that it is near perfect either in content or arrangement. During the 15 years that the author has taught this course the outline has taken many forms and no doubt will continue to change. It is presented rather with the hope that others teaching this or other advanced courses in farm

[1]Contribution from the Department of *Farm Crops and Soils, Iowa State* College, Ames, Iowa. Received for publication October 19, 1931.

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crops will be inspired to publish their outlines or similar material giving others the benefit of their experiences

It will be noted that the outline is divided and subdivided according to fundamental principles involved in breeding rather than by crops After changing back and forth several times between the two methods of procedure, the author is converted to the topical rather than the crop outline This method of presentation ties up to better advantage fundamental principles studied in previous courses in genetics and biology and their application in breeding problems. As the course is now outlined the fundamental principles are briefly reviewed previous to or at the time they are applied in the breeding problems. This makes more evident the scientific basis for our present breeding methods.

The course assumes that all the students have had a good general course in genetics. A few of the graduate students who take the course have had an advanced course in plant genetics, but the course is designed more particularly for the advanced undergraduate or the graduate student who has had only the general course in genetics, together with a good knowledge of crops and botany. In the past 10 years the enrollment in the course in the spring quarter has ranged from 12 to 16, including 2 to 5 graduate students. The undergraduate students have been about equally divided between juniors and seniors and the graduate students generally have been in the first year of their graduate study.

At the end of each chapter or Roman-numeral division of the outline there is a list of references. It will be noted that the references are grouped under the headings "Required reading" and "Optional reading". This is to provide for differences in students in the class with respect to their individual interests. This is especially desirable where there are some graduate students in the class. The total number of references listed would be too great to require of the average undergraduate student, but at the same time the lists of optional readings serve as suggested readings for the student who is above the average or who has a special interest in the breeding work.

Assigned problems have been used rather extensively through the course. The assignments as used during the past year are included at the end of the outline, together with notes as to when the assignments were used in the progress of the course. It will be noted that in some cases the problems were made up with the view of stimulating thought and reading on a topic before taking up that topic in the lecture period, while in other cases the problems have as their purpose the testing of the student's ability to apply knowledge obtained in pre-

vious lectures. In general, the assignments have furnished an important source for discussion material.

The course as now listed in the college catalog carries four quarter credits with three lecture periods and one 2-hour laboratory period each week. As the course has been presented in the past few years the lecture periods have been rather irregularly divided between formal presentations of information, discussions coming from assigned problems or students' questions, and the interpretation and discussion of some of the assigned readings. The laboratory periods are devoted to technic in hybridization, simple biometrical problems, and field work. The course is offered in the spring quarter and the first summer term so that there is ample opportunity for field work. It is necessary to grow some material in the greenhouse for the hybridization studies.

The outline does not show any provision for the consideration of plat technic. The author has found it difficult to interest undergraduate students in discussions of the principles involved in plat technic; and since the graduate students get a course in experimental methods, it has been found desirable to omit this material from the crop breeding course except as it is necessary in connection with discussions of field and laboratory methods. The course in experimental methods is a lecture course carrying two quarter credits and is limited to graduate students who have had some work in statistical methods This makes it possible to give the graduate students much more comprehensive and fundamental material on plat technic than could be included in the course in crop breeding.

OUTLINE OF COURSE

I. Introduction
  A. Meaning of "crop breeding"
    1. Scope and methods
    2. Relation to other agronomic work
  B. Problems in crop breeding
    1. Economic production
    2. The world's food supply
    3. Breeding for special adaptations and uses
    4. Breeding for disease resistance

Required reading

1. Jones, D. F. Genetics in Plant and Animal Improvement. John Wiley and Sons, New York. Chapt. I. 1925. .

Optional reading

1. Shepperd, J. H. The Story of an Everlasting Clover. Breeders' Gazette, 83:845–846. 1923. (June 21).

2. Anonymous. Who Put "King Corn" on the Throne? Breeders' Gazette, 83:69–70. 1923. (Jan. 18).
3. Wentz, J. B. Some New Plant Varieties in Iowa. Seed World, 22:7–9. 1927. (Dec. 2).
4. DeKruif, Paul. Hunger Fighters. Harcourt, Brace and Company, New York. Chapts. I and II. 1928.

II. Early history of plant breeding
- A. Artificial pollination of the date palm by people of Egypt and Mesopotamia as early as 700 B. C.
- B. Reference to male and female date palms by Assyrians.
- C. The suggestion of Sir Thomas Millington that the stamens served as male organs developed by Nehemiah Grew in 1676.
- D. Demonstration of sex in plants by Rudolph Jacob Camerarius in 1694.
- E. Plants first artificially crossed by Thomas Fairchild in 1719.
- F. The pollination of plants by insects noted by Philip Miller in 1731.
- G. Extensive crossing experiments conducted by J. G. Koelreuter in 1761 and following few years.
- H. A. F. Wiegmann's hybridization studies in response to the prize offered in 1819 by the Royal Prussian Academy for an answer to the question, "Does hybridization occur in the plant kingdom?"
- I. Extensive hybridization studies of C. F. Gartner published in 1849.
- J. Works of Thomas A. Knight, William Herbert and John Goss in the early part of the nineteenth century.
- K. John LeCouteur's wheat breeding work about 1800.
- L. Small grain breeding work of Patrick Shirreff and F. F. Hallett about the middle of the nineteenth century.
- M. Charles Darwin's work with hybrids reported in 1856.
- N. Charles Naudin's hybridization studies reported in 1865.
- O. Gregor Mendel's paper published in 1865.
- P. Hjalmar Nilsson's elementary species observed in 1890.
- Q. Wheat breeding work of W. M. Hays started in 1891.
- R. The mutation theory by Hugo DeVries in 1901.
- S. The pure line theory by W. Johannsen, published in 1903.

Required reading

1. Hayes, H. K., and Garber, R. J. Breeding Crop Plants. McGraw-Hill Book Co., New York. Chapt. I. 1927.

Optional reading

1. Roberts, H. F. Plant Hybridization before Mendel. Princeton University Press., Princeton. 1929.
2. Roberts, H. F. The Founders of the Art of Breeding. Jour. Heredity, 10:99–106, 147–152, 229–239, 257–270. 1919.

III. Pure line theory and crop breeding
   A. Galton's law of regression
   B. Johannsen's bean experiment
   C. Definition of a pure line
   D. Stability of pure lines
   E. Composition of a field of wheat or oats as compared to a field of corn
      1. Application in source of seed
         a. Corn
         b. Oats and wheat
         c. Clover and alfalfa
         d. Potatoes
   F. Application of the pure line idea in small grain breeding
      1. Historical developments
      2. Field methods now in use
   G. Outstanding accomplishments in pure line selection
   H. Limitations of pure line selection.

Required reading

1. Jones, D. F. Genetics in Plant and Animal Improvement. John Wiley & Sons, New York. Chapt. IX. 1925.
2. Love, H. H., and Craig, W. T. Methods Now in Use in Cereal Breeding and Testing at the Cornell Agricultural Experiment Station. Jour. Amer. Soc. Agron., 16:109–127. 1924.

Optional reading

1. Newman, L. H. Plant Breeding in Scandinavia. The Canadian Seed Growers' Association, Ottawa, Canada. Chapts. III and VI. 1912.
2. DeVries, Hugo. Plant Breeding. The Open Court Pub. Co., London. Chapt. II. 1907.
3. Hayes, H. K., and Garber, R. J. Breeding Crop Plants. McGraw-Hill Book Co., New York. Chapt. VII. 1927.
4. Walter, H. E. Genetics. The Macmillan Co , New York. Chapt. VI. 1930.
5. Hays, W. M. Wheat. Minn. Agr. Expt. Sta. Bul. 62. 1899.

IV. Hybridization in crop breeding
   A. Review of law of segregation and recombination
   B. Xenia
      1. Definition
      2. Examples
      3. Cause
      4. Applications in crop breeding technic
   C. Combination of characters
      1. Possibilities
      2. Examples
      3. Limitations

a. Only closely related types can be crossed
b. The number of plants to be grown and the resulting amount of detailed labor increases very rapidly with the increase in number of heritable factors involved.
c. Linkage
(1) Illustration of effect of complete and partial linkage upon results
d. Physiological limitations

D. Quantitative characters
1. Definition and examples
2. Theoretical consideration
a. Multiple factor hypothesis
b. Illustrative distributions in hybrid populations
(1) Assuming no dominance
(2) Assuming dominance
3. Methods of studying quantitative characters in breeding investigations

E Hybridization in small grain breeding
1. Mendelian method
2. Bulk growing followed by isolation of pure lines
a. Factors affecting the rate at which hybrid material becomes homozygous
(1) Number of pairs of genetic factors involved
(2) Lethal factors
(3) Semi-lethal factors
(4) Hybrid vigor
(5) Linkage
3. Combination of methods 1 and 2
4. Repeated back crossing followed by isolation of pure lines
5. Outstanding accomplishments in the hybridization of small grains

F. Hybrid vigor
1. Definition
2. Examples
3. Cause
a. Physiologic stimulation
b. Theory of heterozygosis
c. Dominance of growth factors
d. Linkage of dominant growth factors
e. Collin's suggestion

G. The application of hybrid vigor in corn breeding
1. Variety crosses
2. Crosses between selfed lines
a. History
(1) East's and Shull's self-pollination studies (1905)
(2) Shull's crosses
(3) Method outlined by Shull (1909)
b. Methods in corn breeding based on use of selfed lines

(1) Production of selfed lines
(a) Source of material
(b) Technic of self pollination
(c) Number of years to self pollinate
(d) Bases for selection of selfed lines
(2) Methods of making the crosses
(3) Testing the crosses for yield
(4) Methods of finding valuable "sires"
(5) Improvement of selfed lines
c. Commercial use of hybrids between selfed lines
(1) Production and distribution of selfed lines
(2) Production of hybrid seed
(a) Single crosses
(b) Double crosses
(c) Crosses between advanced-generation hybrids
(3) Relations of the experiment station, commercial seed producers and farmers in the hybrid corn breeding program

H. Present status of corn improvement
1. For the experiment stations
2. For farmers
3. For the seed producer

I. Studies of selfed lines in other crops than corn
1. Alfalfa
2. Red clover
3. Timothy
4. Perennial rye grass
5. Rye
6. Cotton
7. Sunflowers
8. Potatoes

Required reading

1. Jones, D. F. Genetics in Plant and Animal Improvement. John Wiley and Sons, New York. Chapt. IV.
2. Babcock, E. B., and Clausen, R. E. Genetics in Relation to Agriculture. McGraw-Hill Book Co., New York. Chapt. X. 1918. (Chapt. XIX in 1927 edition).
3. Leighty, C. E. Theoretical Aspects of Small Grain Breeding. Jour. Amer. Soc. Agron., 19:690–704. 1927.
4. Love, H. H. A Program for Selecting and Testing Small Grains in Successive Generations Following Hybridization. Jour. Amer. Soc. Agron., 19:705–712. 1927.
5. Harlan, H. V., and Martini, M. L. A Composite Hybrid Mixture. Jour. Amer. Soc. Agron., 21:487–490. 1929.
6. Richey, F. D. The Experimental Basis for the Present Status of Corn Breeding. Jour. Amer. Soc. Agron., 14:1–17. 1922.

7. Jones, D. F. Selection in Self-fertilized Linea as the Basis for Corn Improvement. Jour. Amer. Soc. Agron., 12:77–100. 1920.
8. Hayes, H. K. The Commercial Use of Double Crossed Corn in Minnesota. Jour. Amer. Soc. Agron., 22: 606–613. 1930.

Optional reading

1. Hayes, H. K., Garber, R. J., and Harlan, H. V. Breeding Small Grains in Minnesota. Minn. Agr. Expt. Sta. Bul. 182. 1919.
2. Harlan, H. V., and Pope, M. N. The Use and Value of Backcrosses in Small Grain Breeding. Jour. Heredity, 13:319–322. 1922.
3. Hayes, H. K. Breeding Improved Varieties of Smooth Awned Barleys. Jour. Heredity, 17:371–381. 1926.
4. Florell, V. H. Bulked-population Method of Handling Cereal Hybrids. Jour. Amer. Soc. Agron., 21: 718–724. 1929.
5. Briggs, F. N. Breeding Wheats Resistant to Bunt by the Backcross Method. Jour. Amer. Soc. Agron., 22:239–244. 1930.
6. Jones, D. F. Connecticut Round Tip Tobacco. Conn. Agr. Expt. Sta. Bul. 228. 1921.
7. DeKruif, Paul. Hunger Fighters. Harcourt, Brace and Company, New York. Chapts. VI and VII. 1929.
8. Richey, F. D. Corn Breeding. U. S. Dept. of Agr. Bul. 1489. 1927.
9. Jones, D. F., and Mangelsdorf, P. C. Crossed Corn. Conn. Agr. Expt. Sta. Bul. 273. 1926.
10. Woodworth, C. M. A Program of Corn Improvement. Ill. Agr. Expt. Sta. Cir. 284. 1924.
11. Kiesselbach, T. A. The Use of Advanced-generation Hybrids as Parents of Double Cross Seed Corn. Jour. Amer. Soc. Agron., 22:614–626. 1930.
12. Richey, F. D. The Convergent Improvement of Selfed Lines of Corn. Amer. Nat., 61:430–449. 1927.
13. Kirk, L. E. Self-fertilization in Relation to Forage Crop Improvement. Sci. Agr., 8:1–40. 1927.

V. Mutations and their place in crop breeding
   A. Gene mutations
   B. Chromosome aberrations
   C. Bud mutations
   D. Chimeras
   E. Graft hybrids
   F. Frequency of mutations
   G. Inducing mutations by external agencies
   H. Uses and value of mutations in crop breeding

Required reading

1. Jones, D. F. Genetics in Plant and Animal Improvement. John Wiley and Sons, New York. Chapt. VII. 1925.
2. Stadler, L. J. Some Genetic Effects of X-rays in Plants. Jour. Heredity, 21:3–19. 1930.

Optional reading

1. Hayes, H. K., and Brewbaker, H. E. Frequency of Mutations for Chlorophyll-deficient Seedlings in Maize. Jour. Heredity, 15:497–502. 1924.
2. Blakeslee, A. F., and Belling, John. Chromosomal Mutations in the Jimson Weed, *Datura Stramonium*. Jour. Heredity, 15:195–206. 1924.
3. Garber, R. J. The Nature and Significance of Mutations in Present Day Breeding Methods. Sci. Agr. 9:133–143. 1928.

VI. Breeding for special adaptations and uses
- A. Disease resistance
  1. Accomplishments and possibilities
  2. Difficulties encountered
     - a. Number of diseases
     - b. Linkage
     - c. Physiologic specialization
     - d. Introduction of new physiologic forms
     - e. Mutations of parasites
     - f. Hybridization of parasites
     - g. Limited knowledge of complexity and nature of disease resistance.
- B. Insect resistance
- C. Drought resistance
- D. Winter hardiness
- E. Spring and winter habit
- F. Chemical composition
- G. Milling quality in wheat

Required reading

1. Hayes, H. K. Inheritance of Disease Resistance in Plants. Amer. Nat., 64:15–36. 1930.
2. Garber, R. J., and Quisenberry, K. S. Breeding Corn for Resistance to Smut. Jour. Amer. Soc. Agron., 17: 132–140. 1925.
3. Clark, J. A. Breeding Wheat for High Protein. Jour. Amer. Soc. Agron., 18:648–661. 1926.

Optional reading

1. Quisenberry, K. S., and Clark, J. A. Breeding Hard Red Winter Wheats for Winter Hardiness and High Yield. U. S. Dept. of Agr. Tech. Bul. 136. 1929.

2. Stakman, C. E., Christensen, J. J., Eide, C. J., and Peturson, Bjorn. Mutation and Hybridization in *Ustilago zea*. Minn. Agr. Expt. Sta. Tech. Bul. 65. 1929.
3. Marston, A. R. Breeding Corn for Resistance to the European Corn Borer. Jour. Amer. Soc. Agron., 22: 986–992.

ASSIGNED PROBLEMS

1. To be given just before "Application of pure line idea in small grain breeding."
   Outline step by step the procedure you would follow in applying the pure line idea in a wheat breeding program.
2. To be given just before "Limitations of pure line selection."
   A plant breeder in the past twenty years has isolated and tested 20,000 selections from a certain variety of oats. In this time he has isolated four superior lines. Should he continue to make selections from this variety with the hope of finding more superior lines?
3. To be given after discussing xenia.
   When you cross flint corn onto flour corn the hybrid seeds harvested are floury. When you cross flour corn onto flint corn the hybrid seeds harvested are flinty. When seed from either of the above crosses is planted and the resulting plants selfed you harvest ears showing 1:1 ratios of floury and flinty seeds. Explain these results.
4. To be given after "Combination of characters."
   Imagine you have tall black and short white strains of oats and you want a short black strain. Assume black and tall to be dominant and use the following symbols.

   B = black T = tall
   b = white t = short

   a. Assuming independent inheritance, what percentage of the plants will be of the desired type in the F_2 generation and how many of these will breed true in the F_3 generation?
   b. Assuming linkage between the factors for stature and color with 20 percent of crossing over, what percentage of the F_2 plants will be of the desired type and what percentage of the desired type will breed true in the F_3 generation?
5. To be given after discussing quantitative characters.
   a. Plant X is 30 inches tall and of genetic constitution AABBCC
      Plant Y is 18 inches tall and of genetic constitution aabbcc

      A = 5 b = 3
      a = 3 C = 5
      B = 5 c = 3

Assuming no dominance, accumulative effect of factors and independent inheritance, show what you will obtain in F_1 and F_2 generations.

b. Plant X is 30 inches tall and of genetic constitution AABBCC
Plant Y is 18 inches tall and of genetic constitution aabbcc.

A = 10	b = 6
a = 6	C = 10
B = 10	c = 6

Assuming complete dominance and independent inheritance show what you will obtain in F_1 and F_2 generations.

6. To be given before "Hybridization in small grain breeding." Imagine that you made a cross ten years ago between two distinct types of wheat differing in a number of characters. You succeeded in obtaining one hybrid seed and grew an F_1 plant from this one seed. The next spring you planted the seed from this F_1 plant and grew an F_2 generation of 100 plants in a small plot. You harvested these F_2 plants, threw them all together and threshed out the seed. In each succeeding year you planted a plot or field of this hybrid wheat.
Describe as well as you can what genetic changes have taken place in this wheat and what kind of a population it now represents.

7. To be given after discussing the factors which affect the rate at which hybrid material becomes homozygous.
   a. You have an F_1 plant hybrid for three pairs of factors. Assuming self-pollination of all plants, calculate the percentage of individuals which will be homozygous in the F_4 generation.
   b. You have an F_1 plant hybrid for one pair of factors. Assuming self-pollination of all plants and that all hybrid plants are twice as productive as the homozygous plants, calculate the percentage of homozygous plants in the F_4 generation.
   c. You have an F_1 plant hybrid for two pairs of factors. Assuming linkage between the two factors with ten percent of crossing over, calculate the percentage of individuals which will be homozygous in the F_2 generation.

8. To be given before the discussion on hybrid vigor. Are genetic factors which retard growth and yield in corn more liable to be dominant or recessive? Explain why this is true.

9. To be given just after discussing hybrid vigor.
Would it be possible to find an inbred strain of corn which would yield higher than the variety from which

it came? Explain how this would or would not be possible.

10. To be given after "Commercial use of hybrids between selfed lines."
    a. Give a genetic explanation as to why the farmer should not save seed from a cross between selfed lines of corn.
    b. Which would ordinarily give less disastrous results—to save seed from a single or a double cross? Explain.
11. To be given after "Commercial use of hybrids between selfed lines."
    The experiment station has found a double cross which it is recommending for use over an area of the state which normally grows three million acres of corn. The Iowa Corn and Small Grain Growers' Association has proposed that the experiment station turn over to them the four selfed lines used in this double cross and that they will produce the single crosses to be distributed to farmers or to seed producers who in turn will produce the double crossed seed for planting in the adapted area. Assuming that all farmers in the adapted area use the double-crossed seed to plant their fields, how many bushels of each of the single crosses will the Corn and Small Grain Growers' Association have to produce?
12. To be given at any time after finishing the discussions on corn breeding.
    Why is it that we continue to find an occasional red ear in a strain of corn when it is know that no red seed has been planted for at least thirty years?
13. To be given any time after finishing the discussions on corn breeding.
    a. You made a cross between normal (LgLg) liguleless and (lglg) corn.
        (1) Assuming no selection and that all plants are equally fertile and productive, what proportion of liguleless plants will you have in the F_4 generation?
        (2) Assuming that you rogue all the liguleless plants from your field before pollination, what proportion of liguleless plants will you have in the F_4 generation?
    b. You made a cross between red pericarp (PP) and colorless pericarp (pp) corn.
        (1) Assuming no selection and that all plants are equally fertile and productive, what proportion of red pericarp ears will you have in the F_4 generation?

(2) Assuming that all colorless pericarp seed is discarded, what proportion of red pericarp ears will you have in the F_4 generation?

14. To be given any time after the discussions on corn breeding.
Write a reply to the following letter which was received from an Iowa farmer.

Gentlemen:

I have a pure yellow corn grown in 1929 on corn stalk ground of 1928 which had a few hills of black sweet corn on it. Could this yellow corn be called pure by removing an odd black kernel which must have come from volunteer corn, probably not more than five or six kernels to a hundred ears?

Thanking you in advance for any information given,

Yours truly,

15. To be given any time after the discussions on corn breeding.
Write a reply to the following letter which was received from an Iowa farmer.

Dear Sir:

In passing through my fields in the late summer I noted a considerable proportion of barren stalks, and I have been endeavoring to discover some remedy. On the principle that like produces like, would not the pollen from a barren stalk falling upon the ear of an adjoining fruitful stalk have a tendency to produce some barren stalks should that ear be selected for seed? Has a test of this sort been made at the Iowa State College?

Also, has a test been made of going through the portion of the field from which seed is to be selected and detassel the barren stalks before the pollen ripens? Would you deem it worth the trouble?

Thanking you for the favor of your reply,

Yours truly,

16. To be given after discussing chromosome aberrations. Explain how it might be possible to produce an absolutely pure line in a single generation from hybrid material by taking advantage of a certain chromosome aberration.

DIFFERENCES OF INJURY BY FROST TO WHEAT PLANTS GROWN COMPARABLY[1]

L. R. WALDRON[2]

Recently, Waldron[3] presented data showing the effect upon the yield of spring wheat from frost injury taking place during the early stages of growth. Yield differences between the frosted and the normally produced crop of the Hope variety were in the neighborhood of 14 bushels per acre, equivalent to a loss of 37%. Conditions which obtained in 1931 allowed the writer to secure further information regarding spring frost injury.

EXPERIMENTAL WORK

One of the wheat nurseries grown by the writer in 1931 consisted of rows of a rod or less in length which were the increases of individual F_4 plant selections from certain crosses where the Hope variety was used as one parent. In addition to these hybrid selections the nursery contained occasional rows of the two varieties Ceres and Hard Federation. The wheat was sown April 1 and 2 which was a comparatively early date. Emergence took place from April 14 to 18 While the soil was sufficiently moist for complete germination, this moisture was not added during April. The total precipitation for the month was but 0.46 inch coming at three different times. The sub-freezing temperatures injuring the plants occurred from April 20 to 27. The minimum temperatures[4] for this period were as follows:

	April							
Date.....	20	21	22	23	24	25	26	27
Temp. F°...	27	24	23	21	22	23	19	24

Observations indicated that the severest damage took place during the night when the temperature fell to 19°. After the period of low temperatures it was found that in many of the rows a certain proportion of the plants showed freezing effects while other plants scattered through the row were apparently uninjured. It was thought, whatever the cause of the differences in injury, that these frosted and unfrosted plants might afford information as to the effect of freezing

[1]Contribution from the Department of Agronomy, North Dakota Agricultural Experiment Station, Fargo, N. Dak. Published with the approval of the Director. Received for publication November 2, 1931.

[2]Plant Breeder.

[3]WALDRON, L. R. Frost injury to spring wheat with a consideration of drouth resistance. Jour. Amer. Soc. Agron., 23:625–637. 1931.

[4]Data taken from the official U. S. Dept. of Agriculture Weather Bureau records.

upon the further development of the plant, particularly in regard to yield. Rows were selected and individual plants were tagged by means of strings tied around each plant. Only two classes were used, plants apparently uninjured and plants distinctly hit by the freezing temperatures. Strings of two colors and weights were tied loosely around the base of the young plant. These strings were replaced by others at a later stage to avoid injury to the growing plant. All

TABLE 1.—*Comparative amounts of injury received in two rows of wheat from two freezing periods.**

Class	Row 358		Row 361	
	Group U	Group I	Group U	Group I
0	22	16	17	22
1	9	25	14	17
2	25	28	19	28
3	2	44	2	26
Totals	58	113	52	93

*Not all plants were tagged.

plants in the experiment had similar treatment and mechanical damage to the plants was thought to be minimal. Two rows were selected among the hybrids for tagging and two rows of the Hard Federation were similarly taken As the hybrid plants had Hope as one parent, which is susceptible to injury from frost, the plants in the hybrid rows which showed frost susceptibility might have carried this trait as a heritable one. It is not clear that this would have mattered particularly in this study unless the genes responsible for susceptibility to frost were also responsible for, or linked with, lessened height or diminished yield. The Hard Federation rows would probably provide a correcting factor if any were needed.

On the night of May 6 a minimum temperature of 24° was recorded, causing additional injury to the wheat. Three additional hybrid rows were picked out for tagging. As it was possible on May 7 to distinguish between the injuries caused by the first and second freezes, an attempt was made to analyze the amount of injury in two of the earlier tagged rows resulting from the two freezes. In each of the two rows, shown in Table 1, two groups of plants are shown, group U, uninjured in the first series of frosts, and group I, injured in the first frosts. Class 0 indicates the plants not injured in the frost recorded May 7, and classes 1, 2, and 3 indicate increasing degrees of injury from the frost of May 7.

Some of the tagged plants were omitted from Table 1 as being difficult to classify. A majority of the plants classified were found to

have been injured by the April freezes, totals of I columns. Of those plants uninjured by the April frosts, only 2 in each row were severely injured by the May frost. A rather high proportion of the plants injured in the first frosts were severely injured in the May freeze, class 3 of I columns. It is evident that the means of the I columns are the larger of the two pairs and calculation shows them to be significantly larger. On May 14, 21 plants tagged as injured by the April frosts

FIG. 1.—Frozen (2) and unfrozen (1) wheat seedlings.

were found to be dead. The evident injury to the frosted plants consisted of frozen leaf tissue. Fig. 1 shows three injured and three noninjured plants from one of the rows as photographed May 4. The frozen tissue is readily distinguished.

HARVEST DATA

The plants were carefully pulled when ripe, separated into the two groups, and stored until detailed notes were taken. Data were taken on height, number of fertile and sterile culms, total weight of threshed grains, with the number of plants and heads from which the grain was threshed, and weight of the grain per 1,000 kernels. In taking these data, the height and stooling data were inadvertently omitted from one pair of Hard Federation bundles coming from one row. The wheat used for planting, other than the Hard Federation, was inoculated for bunt. The data secured on the paired samples A and B, tagged as not injured and injured by frost, are shown in Table 2.

Table 2.—*Height, number of culms, grain per plant, and other data from non-frosted (A) and frosted (B) wheat plants grown comparatively.*

Row	No. plants harvested	Culms				No. of bunted plants	No. of sterile culms per plant	No. of plants threshed	Grain				
		Height, cm	Stand. dev.	Number	Stand. dev.				No. of heads	Total weight, grams	Per plant, grams	Per head, grams	Weight per 1,000 kernels, grams
358A	53	95.11±0.81	9.63±0.64	3.72±0.18	1.88±0.12	16	0.3	51	152	109.21	2.14	0.72	31.50
358B	58	84.07±1.65	18.43±1.16	1.93±0.11	1.24±0.08	7	0.4	45	78	52.06	1.16	0.67	31.80
361A*	33	80.49±0.70	5.84±0.49	4.55±0.18	1.52±0.13	—	0.6	30	127	78.50	2.62	0.62	32.70
361B	63	73.59±0.68	7.96±0.48	2.49±0.15	1.74±0.11	—	0.4	59	123	79.14	1.34	0.64	32.05
369A	65	97.62±0.83	9.81±0.58	4.72±0.14	1.68±0.10	2	0.4	65	270	192.00	2.95	0.71	33.70
369B	61	87.74±1.35	15.47±0.95	2.15±0.10	1.16±0.07	1	0.1	50	104	66.35	1.33	0.64	33.45
271A	24	97.00±1.22	8.66±0.86	3.75±0.17	1.20±0.12	7	0.6	20	53	43.60	2.18	0.82	31.35
271B	63	88.19±1.19	13.88±0.84	1.84±0.08	.91±0.06	35	0.4	26	47	34.35	1.32	0.73	30.50
272A	50	92.50±0.76	7.90±0.54	3.94±0.13	1.38±0.09	11	0.3	44	151	111.29	2.53	0.74	33.10
272B	45	82.00±1.70	16.77±1.21	2.18±0.10	1.00±0.07	12	0.3	33	69	44.73	1.36	0.65	32.85
273A	14	95.93±1.42	7.60±0.97	5.07±0.29	1.54±0.20	6	0.4	11	44	31.21	2.84	0.71	30.30
273B	20	87.50±1.97	12.74±1.39	2.20±0.17	1.08±0.12	9	0.1	12	22	13.79	1.15	0.63	30.75
377A*	—	—	—	—	—	—	—	53	204	133.73	2.52	0.66	33.20
377B	—	—	—	—	—	—	—	64	141	79.75	1.25	0.57	31.20

*Hard Federation.

Table 2 shows clearly that the unfrosted (A) samples had distinctly taller plants with more heads per culm and with more grain per plant than the frosted (B) samples. The B samples, because of the presence of comparatively short culms, in some cases below 40 cm, have higher standard deviations than the A samples. Sterile culms were not relatively more abundant on the frosted plants. In five out of the seven cases, weight per 1,000 kernels was less for the frosted plants.

In Table 3 are shown differences of means and the percentage defects that the B means are in terms of the A means.

TABLE 3.—*Differences of means of Table 2, their Diff./P.E. ratios, and percentage defects of the B series.*

Row No.	Height of plant			No. of culms			Grain	
	A-B, cm	Diff./P.E.	Defect of B %	A–B	Diff./P.E.	Defect of B %	A–B grams	Defect of B %
358	11.04±1.84	6.0	11.6	1.79±0.21	8.5	48.1	0.98	45.8
361	6.90±0.98	7.0	8.6	2.06±0.24	8.6	45.3	1.28	48.9
369	9.88±1.59	6.2	10.1	2.57±0.17	15.1	54.5	1.62	54.9
271	8.81±1.70	5.2	9.1	1.91±0.19	19.0	50.9	0.86	39.5
272	10.05±1.86	5.7	11.4	1.76±0.16	11.0	44.7	1.17	46.3
273	8.43±2.43	3.5	8.8	2.87±0.34	8.4	56.6	1.69	59.5
377							1.27	50.4
Av.	——	5.6	9.9	——	11.8	50.0	——	49.9

The lowest ratio of the difference in any pair of means to its probable error is 3.5, while the averages of the two sets are 5.6 and 11.8. The differences are thus significant in all cases and very highly so in all cases but one. The percentage defect of grain per plant in the B samples closely follows the percentage defect in number of fertile culms, except in the case of row 271. The disparity in this instance is likely due to the large number of bunted plants in the B samples. Bunted heads were eliminated before threshing and the heavy elimination in this sample tended to augment the amount of grain per plant.

The foregoing evidence shows rather plainly that wheat plants subject to spring frosts may be rather seriously injured. It is not evident from the foregoing study that the *yield per acre* would be decreased by the losses indicated, but the inference is clear that in a field of wheat a certain proportion of the plants would give a decreased yield. The argument might be advanced that the uninjured plants would compensate for the lessened growth of the injured plants in that they would be provided with additional space and food material. The presence of the weakened plants would not allow full

compensation to be made and would tend to retard the maximum development of the non-frozen plants. Fields showing frost injury of all or nearly all of the plants would show a depression in yield. In a case like the one under consideration, where rather more than half of the plants showed frozen leaf areas, it is very likely that the yield would undergo a decrease from the potential yield of the pre-frost period, but such decrease would likely not be commensurate with the grain loss per plant. It is recognized that low growing temperatures in the early life history of the spring-sown wheat plant is of advantage in securing good harvest returns. Obviously the plants, in a period of cold weather, are accepting hazards as the temperatures may fall below the freezing point sufficiently to injure the crop.

It was stated by Waldron[5] that varieties of spring wheat show differences as a whole in their reaction to spring frosts. In the present instances there appear to be differences within a variety. Five of the rows, it is true, were made up of plants of the F_5 generation, but as these rows were the offspring of single plant ancestors they may have been as genetically pure and uniform as the average named variety.

The variety Hard Federation apparently duplicated the results from the hybrid rows. While the present study merely states the fact of differences within a variety and does not attempt to make a closer approach to the problem, a few ideas are suggested. It is presumed that the plus and minus reactions toward frost were causal, that is, the plants somehow differed chemically, a difference colloidal in nature. This chemical difference may have developed after the seeds were planted due to different soil reactions, or the differences may have been inherent in the seeds. In the latter case, which seems rather the more probable, the differences may have been Mendelian in character, brought about by genic differences. Also, the differences may lie exclusively in the cell sap and not conditioned by chromosome carriers. Correns[6] has reviewed the literature of non-Mendelian inheritance and has shown that in a number of cases plant characters are to be explained on the basis that plastids are carried in the plasma through successive generations. More recently, Buchinger[7] has reviewed the literature of a special phase of non-Mendelian inheritance, that relating to the osmotic pressure of the cell sap or

[5] *Loc. cit.*

[6] Correns, C. Über nichtmendelnde Vererbung. Zeitschr. Indukt. Abstam.-u Vererbungl. Supplementb., 1:131-168. 1928.

[7] Buchinger, A. Die Zusammenhange zwischen Saugkraft und plasmatischer Vererbung. Genetica, 12:539-561. 6 figs. 1930.

"Saugkraft." Seeds germinated in sugar solutions show different capacities or water absorption. These capacities are considered to be characteristic of the plant throughout its life history and capable of being carried over to the next generation, at least through the embryo sac. Different workers have presented evidence to show that seedlings showing different degrees of osmotic pressure likewise show quantitative and qualitative differences during their subsequent life histories. Desirable agronomic characters are generally associated with high osmotic pressure. It is evident that additional work will be needed to establish to what extent different osmotic pressures are inherited.

SUMMARY

As a result of severe April and May frosts a certain proportion of plants in rows of Hard Federation and F_5 hybrid selections were injured. Uninjured and injured plants of the two groups were labeled and sorted at harvest. A study made upon these showed that the injury persisted during the life of the plant with a marked decrease in yield. The injured plants were nearly 10% less in height than the uninjured plants, while the deficiency in the number of fertile culms and in grain per plant was at or near 50%. Injuries of this sort must have an influence upon the yield per acre as any increased growth of the uninjured plants above what would have occurred normally could not compensate for the losses of the injured plants, which would remain as competitors. The value of varieties resistant to frost is evident.

RECURVING IN SORGHUMS[1]

John H. Martin[2]

The panicles of some sorghums, particularly those of Gooseneck sorgo and most varieties of milo and durra, frequently become recurved after emergence from the sheath. In broomcorn "crooked" brush is a common occurrence.

In grain sorghums, especially, the recurving is undesirable because occasional heads snap off after bending over and because of the increased difficulties and losses in harvesting pendant heads. Recurved or pendant heads are less accessible than erect heads in harvesting by hand. In machine harvesting the severed recurved heads frequently catch on the reel of the header or combine and are thrown out on the ground. Rarely, if ever, are all the heads in a field

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication November 2, 1931.

[2]Senior Agronomist in Charge of Grain Sorghum and Broomcorn Investigations.

fully or even partly recurved, and the consequent irregularity in the position of the heads also increases the difficulty of harvesting.

The "crooks" in broomcorn are not considered worth harvesting except when prices of brush are high. When the crooked brush is used in broom making, the crook and the portion of brush below it are discarded.

Recurving ("goosenecking" or "crooknecking") is most prevalent under conditions favoring rapid and abundant growth, such as are provided by ample moisture, thin stands, and fertile soil. Conner and Karper[3] showed that pruning the roots and decreasing the feeding area of the plants increased the percentage of erect heads. Martin[4] showed that a low percentage of erect heads usually is associated with large heads and high yields.

Conner and Karper stated: "It seems conclusive that in milo a tightly inrolled upper leaf sheath seems to be associated with a large number of pendant heads." They observed that in milo the sheath opened at the side instead of completely unfolding as it does normally in kafir and that when the head is forced out of the side of the sheath an inrolling takes place. They observed no difference in the tenderness of the peduncle in milo and kafir, either type recurving when a section was removed from the back of the upper leaf sheath.

Brief studies and observations of recurving in sorghums have been made by the writer during several seasons but particularly at the Fort Hays, Kans., Branch Experiment Station in the summer of 1931. The removal of the sheath during the heading period caused the immediate recurving of either kafir or milo. At the heading stage the peduncle, especially at the base where growth is taking place, is soft, very flexible, and easily broken. As the peduncle gets older it loses its softness and flexibility. This hardening was found to be closely associated with the lignification of the fibrovascular bundles. Staining tests of milo peduncles for lignin, using phloroglucin and hydrochloric acid which stains the lignin a bright red, showed the following:

Stage of development	Lignification	
	Top of peduncle	Base of peduncle
One-third out of the boot	Slight	None
One-sixth bloom	Considerable	None
Final bloom	Nearly complete	Very slight
Seeds all formed	Complete	Considerable
Seeds green	Complete	Nearly complete
Seeds in hard dough	Complete	Complete

[3]CONNER, A. B., and KARPER, R. E. The recurving of milo and some factors influencing it. Texas Agr. Exp. Sta. Bul. 204. 1917.

[4]MARTIN, J. H. Plant characters and yield in grain sorghums. Jour. Amer. Soc. Agron., 20: 1177–1182. 1928.

Kafir peduncles showed approximately the same degree of lignification as milo at corresponding stages of development. Broomcorn fibers in varying stages of development also showed variations in lignification similar to those in milo. The lack of lignification in early heading stages apparently explains the flexibility of sorghum peduncles which permits recurving. Lignification begins soon after the head has emerged and the recurved panicles become stiffened. A curved lignified peduncle can not be straightened without breaking.

Since the peduncles of all grain sorghums are flexible at heading time, the differences in recurving must be due to differences in the size and shape of the emerging panicle or in the support given the head and peduncle by the sheath, or both. Conner and Karper attributed the emergence of milo through the side of the sheath to the tight infolding at the tip of the sheath which prevents unfolding. The writer has observed, however, that the milo sheath unfolds readily if the head reaches the tip of the sheath before it has been forced out at the side. The sheath seldom inrolls when the milo heads are small but overlaps around the peduncle as on kafir plants. · Inrolling in milo occurs only after the head has been forced out of the sheath and a kafir sheath also will inroll if a head in the "boot" stage is pulled out at the side of the sheath. The heads of kafir and other erect-headed types of sorghum are rarely more than an inch in diameter when they emerge from the sheath and the sheath is large enough completely to surround and support the emerging head and peduncle. Well-developed heads of the recurving varieties of milo and durra, however, may be 2½ inches wide and 1¼ inches thick when they emerge from the sheath. These wide heads seldom are more than half surrounded by the sheath, and the lack of support thus permits the heads to fall out of the sheath and recurve, usually before but occasionally after the head reaches the tip of the sheath. The larger the head the less completely the sheath surrounds it, and the more likely it is to fall out and recurve. Numerous heads of milo in the "boot" have been observed to shake out of the sheath during a brief whirlwind and immediately recurve.

The heads of most recurving varieties may be either inclined or pendant, but a few very compact durras produce peduncles so completely recurved that the center stem of the head is turned in a nearly horizontal position. This extreme recurving apparently is caused by the weight of the head continuing to bend the base of the growing peduncle before lignification has begun. Milo heads which are not recurved usually are at least slightly inclined. This inclination seems to be caused by the head being pushed partly out of the boot or at

least out of line with the culm, owing to the large diameter of the head as compared with that of the enveloping sheath.

Efforts to produce "straightneck" varieties of durra and milo have been under way for many years. A few erect-headed durras have been introduced or selected, but these all have loose slender heads. Continued efforts of investigators 15 to 20 years ago to secure erect-headed milos by selection resulted in complete failure. Crosses between milo and kafir, however, have produced segregates having many milo characters combined with erect heads. Three of these "straightneck" milos, *viz.*, Fargo, Beaver, and Wheatland, are now grown commercially. None of the erect-headed milos has heads so compact as those of the recurving varieties. The more compact erect types of kafir-milo hybrids, such as Beaver milo, have thicker heads in the heading stage and show a greater tendency to incline or recurve than the slender loose-headed types. The selection of thick, compact-headed milos for erectness as formerly recommended[5] appears to be futile.

In broomcorn the weight of the brush and the rapidity of growth at heading time appear to be the chief factors determining the percentage of recurved heads or "crooks." If the brush is too heavy to be supported by the sheath and by the flexible fibers at the base before lignification has developed, then a "crook" is formed. After the fibers are lignified the "crook" becomes fixed or set and can not be straightened.

SUMMARY

Recurving in sorghums is the result of thick heads being forced out of the side of a too narrow sheath while the peduncle is flexible and unlignified.

Selection of compact-headed types of milo or durra for erectness appears to be futile.

Broomcorn "crooks" result from the bending over of a heavy brush before the fibers become lignified.

[5]Ball, C. R. The importance and improvement of the grain sorghums. U. S. D.A. Bur. Plant Ind. Bul. 203. 1911.

Rothgeb, B. E. Milo, a valuable grain crop. U.S.D.A. Farmers' Bul. 1147. 1920.

DIFFERENTIAL RESISTANCE OF INBRED AND CROSSBRED STRAINS OF CORN TO DROUGHT AND HEAT INJURY[1]

MERLE T. JENKINS[2]

In a recent paper[3] it was mentioned that some of the inbred lines and crosses grown at Ames, Iowa, during the season of 1930 showed marked resistance to injury by the hot, dry weather. The crosses of one line in particular were very free from leaf burning. It was thought that it might be of interest to present in more detail some of the evidence of differential resistance to leaf burning which was obtained.

Taking advantage of the opportunity afforded by the extreme season, counts were made on August 5 of the plants with burned upper leaves in three of the six replications of the regular yield comparison of crosses. The percentages of plants with burned leaves for one group of crosses among a number of eight-generation selfed lines and for the parent lines, so far as available, are given in Table 1. They are based on 70 or more plants of the parent lines, except for one line, and on three plats of each cross with a total of 42 three-plant hills. The data for the parent lines are recorded along the lower and right hand margins of the table and those for the crosses at the intersections of the row and column headed with the pedigrees of the parents.

DISCUSSION

There was a very marked difference in the resistance of inbred lines and of their single crosses to the leaf burning common in hot, dry weather. The crosses of line L317B2 were uniformly resistant. In the 10 crosses of which this line was a parent there were no plants with burned leaves. Comparable crosses of line L293A1 were very susceptible to leaf burning. Line L317B2 seems to carry dominant factors for resistance. The cross L317B2 x Mc412A3 was resistant to burning and yet line Mc412A3 itself and all of the other crosses of which it was a parent were very susceptible to burning.

[1]The data on which this paper is based were obtained in connection with the corn improvement project conducted by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station, cooperating. Journal Paper No. B6 of the Iowa Agricultural Experiment Station, Ames, Iowa. Received for publication November 3, 1931.

[2]Associate Agronomist, U.S. Dept. of Agriculture, and Chief in Cooperative Corn Improvement, Iowa Agricultural Experiment Station.

[3]JENKINS, MERLE T., and RICHEY, F. D. Drought in 1930 showed some strains of corn to be drought resistant. U.S. Dept. Agr. Yearbook, 1931:198–200. 1931.

TABLE 1.—*The percentages of plants with burned leaves in a group of inbred lines of corn and the single crosses among them in 1930.*

Pedigree of parental lines	Pedigree numbers of parental lines										Means of crosses	Parental lines
	I168	I227	Dr276A	B1345B	B1349A	Mc398	Mc401A1	Mc412A3	Mc415B	ITE701B		
L289A2	6.4	45.9	0.0	0.0	9.1	58.5	3.4	40.2	0.8	0.8	16.51	64.7
L291	3.0	14.2	7.4	0.0	2.6	5.8	2.7	17.0	0.0	1.8	5.45	—
L292B	21.8	42.2	0.0	0.0	3.6	40.4	2.8	56.0	0.9	6.3	17.40	65.4
L293A1	26.2	86.2	19.2	7.8	85.5	89.7	14.0	81.8	22.1	45.9	47.84	—
L304B	7.2	35.4	5.2	0.0	4.5	4.3	0.0	57.5	1.7	0.0	11.58	6.1
L309	2.5	15.8	2.4	0.0	0.8	12.3	0.0	4.9	0.0	2.5	4.12	—
L317B2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
L324	2.7	10.4	0.0	0.0	1.7	0.8	0.0	19.3	0.0	0.0	3.49	—
L325A	0.0	40.2	0.0	0.0	14.6	10.4	0.0	25.5	0.0	0.0	9.07	9.9
L337	1.9	6.1	0.0	0.0	26.8	37.4	0.9	77.3	9.1	0.8	16.03	—
Means of crosses	7.17	29.64	3.42	0.78	14.92	25.96	2.38	37.95	3.46	5.81	—	—
Parental lines	—	—	—	6.4	65.2	—	0.0	94.5	—	—	—	—

On the other hand, line L293A1 seems to carry somewhat dominant factors for susceptibility. All of the crosses of lines Dr276A, Bl345B, Mc401A1, Mc415B, and ITE701B, except those with L293A1, are quite resistant to burning. Unfortunately, the cross of L293A1 x L317B2 was not grown in 1930. It would have been interesting to observe its performance in regard to burning.

It would seem that a great deal might be accomplished in breeding corn for drought resistance. It is of especial significance in this connection that the crosses of line L317B2, which averaged the most resistant to burning, also averaged the most productive.

SUMMARY

Data on a number of inbred lines and crosses in the corn improvement experiments showed marked differences in resistance to the leaf burning associated with the hot, dry weather of 1930. The 10 crosses of one of the lines were completely free from leaf burning, whereas those of another line ranged from some to many plants with burned leaves in the different crosses. The data indicate that much might be accomplished in the breeding of corn for drought resistance.

AGRONOMIC AFFAIRS

A STUDENT SECTION OF THE SOCIETY

Dr. P. E. Brown has announced the appointment of a special committee to consider the organization of a national student section of the American Society of Agronomy. The committee follows: E. R. Henson, Iowa, *chairman;* H. K. Wilson, Minnesota; F. D. Keim, Nebraska; J. W. Zahnley, Kansas; and G. H. Dungan, Illinois.

THE PROGRAM OF THE CROPS SECTION AT WASHINGTON

Prof. R. J. Garber, chairman of the program committee for the Crops Section of the Society, announces that it is planned to devote a considerable part of the program for that Section at the annual meeting of the Society in Washington next fall to the presentation of original research. The maximum time allowed for the presentation of a paper will be 15 minutes. *The title, author, and time required for presentation of papers should be sent to R. J. Garber, West Virginia University, Morgantown, W. Va., together with an abstract of not more than 200 words.* The latest date on which titles and abstracts of papers to be presented at the Washington meeting will be accepted is October 1, 1932.

To make such a program attractive and successful will require the cooperation of all members of the Society interested in crops science. The program committee is particularly desirous of obtaining short papers presenting original research of particular interest to crops men.

SUMMER MEETING OF THE CORN BELT SECTION OF THE SOCIETY AND OF THE AMERICAN SOCIETY OF PLANT PHYSIOLOGISTS

The summer meeting of the Corn Belt Section of the Society and of the American Society of Plant Physiologists is to be held at the University of Wisconsin, Madison, Wis., July 11, 12, and 13. Headquarters will be at the new Agronomy Building, and it is planned to provide for lodging and meals for the entire group (at very reasonable rates) in the new and modern dormitories which are located on the shore of Lake Mendota on the campus of the College of Agriculture. Hotels, University Club, Memorial Union, and other accommodations are also available.

MONDAY AND TUESDAY MORNINGS

Visits to laboratories and greenhouses to observe technic and work in progress on the following:

1. Studies of nitrogen fixation under the Frasch grant to Wisconsin for research in biochemistry; fungi and azotobacter measurements of soil fertility; and variations among strains of root nodule bacteria.
2. Nature of phosphate and potash fixation in soils amd identification of base exchange materials by petrographic and specific gravity methods.
3. Major soil regions of Wisconsin.
4. Drying equipment for seed corn and for drying grains after fungicidal treatments; environmental relations and the fruiting of alfalfa plants.
5. Special laboratories and equipment for research in biochemistry.
6. Studies of photosynthesis; ultra-violet light investigations.
7. Responses of apple trees to shading and length of day.
8. Cytologic and genetic researches on corn.
9. Inexpensive freezing equipment for low temperature studies; electrical conductivity method of measuring hardiness and for studying the hardening process.
10. Methods for studying the fermentation of tobacco; rotating apparatus for determining the effect of aeration and drying on certain toxic effects in soils.
11. Apparatus and equipment for investigation of radiation effects in metabolism; use of special glasses and lamps for determining the effects of light upon development and composition of plants.
12. Pathological studies with demonstrations of the technic of environmental control; disease studies on cereals; symptoms of hairy root, crown gall, and over-growths.

MONDAY AND TUESDAY AFTERNOONS

Two hours of each afternoon to be spent on the University Farm to observe field work with reference to cereals and forages; disease resistance studies of grains, barley stripe, inbred and hybrid strains of rye, smooth awned barleys; introductions of Russian winter wheats and wheat hybrids, crosses between hard and soft winter wheat for winter hardiness and disease resistance; scab inoculation cages; etc.

Autumnal defoliations of bluegrass and alfalfa in relation to hardiness, winter injury, and to subsequent productivity; symptoms and resistance studies of bacterial wilt of alfalfa; alfalfa breeding and seed production studies; factors influencing the recovery of forages in relation to cutting treatments and environmental conditions.

GROUP MEETINGS

Beginning at 3:15 p.m. Monday, the meeting will be divided into three optional groups as follows:

1. Those primarily interested in soils and in pasture improvement will be provided with a trip to Ft. Atkinson to visit the intensively fertilized and rotationally grazed (Hohenheim) pasture plats and to take part in an informal evening discussion on soil and pasture problems.
2. A group primarily interested in barley developmental work will meet informally for a discussion of the problems in barley breeding.
3. A physiological group will also meet Monday afternoon and evening for an informal discussion under the leadership of a few out-standing physiologists and biochemists.

FIELD TRIPS ON WEDNESDAY

1. For soils men and agronomists, a trip will be provided through the major soil areas of Wisconsin to Hancock, Wis., to observe experimental work on light sandy soils, and thence to Marshfield, Wis., where fertility, forage, and grain problems of the heavy soil types are being studied. This will require all day. For those interested, a return trip on Thursday from Marshfield through the unglaciated regions of western Wisconsin is planned to observe the Federal Erosion Station at LaCrosse and to see outlying field work in erosion control.
2. For physiologists, pathologists, and geneticists, a short field trip is planned to Waupun and Sun Prairie, Wis., to observe the serivce of research to the canning industry of Wisconsin. The problems of the pea canner, a modern pea packing plant, disease resistant strains of canning peas, and how a rapid increase of desirable seed stocks is effected by their culture in New Zealand during the winter period of Wisconsin will be seen.

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THE QUANTITATIVE DEVELOPMENT OF TOPS AND ROOTS IN BLUEGRASS WITH AN IMPROVED METHOD OF OBTAINING ROOT YIELDS[1]

C. J. WILLARD AND G. M. McCLURE[2]

In connection with a project on the effect of various treatments on the underground parts of bluegrass, which it has been necessary to discontinue, the writers secured data on methods of sampling and on the establishment of a bluegrass stand which seem worth publishing at this time.

METHODS OF SAMPLING

The senior author has made studies of legume roots by harvesting square yard samples. The first effort at washing out the underground parts of bluegrass showed that so large a sample as this could not be used because it required too much time to wash the soil out of the sample.

Preliminary trials of harvesting a number of square foot areas of bluegrass sod to determine the magnitude of the sampling error from areas of this size were made by the junior author. Two series of samples were taken. One (series A), comprising eight samples from an area of bluegrass sod which had been cut only a few times in 1928 with a field mower, was secured on March 6, 1929. The other (series B), comprising nine samples, was from an eight-year-old pasture in which bluegrass predominated. The area had been frequently mowed with a lawn mower during 1928. The samples were chosen from areas on which the turf appeared to be uniform. All samples were taken to a depth of 6 inches.

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio, in cooperation with the Ohio State University, Columbus, Ohio. Received for publication November 18, 1931.

[2]Associate and Assistant in Agronomy, Ohio Agricultural Experiment Station, and Professor of Farm Crops and Assistant Professor of Soils, Ohio State University, respectively.

Various methods of separating the tops from the roots were tried, but the one which finally proved feasible was to cut the tops from the underground parts at the surface of the ground with a sharp knife or shears. It was not feasible to cut the tops from the roots after digging, nor did it prove feasible to separate rootstocks from true roots or from the underground parts of the culms. The term "roots," therefore, includes all the underground parts of the grass, *viz.*, true roots, rootstocks, and underground culm bases.

TABLE 1.—*Yields in pounds per acre of trial samples of bluegrass.*

Sample No.	Series A		Series B	
	Crude roots	Corrected	Crude roots	Corrected
1	12,960	7,860	7,200	5,090
2	9,320	7,000	7,100	5,680
3	9,320	8,440	8,930	5,850
4	9,220	6,620	5,290	4,320
5	7,690	6,150	4,320	3,840
6	9,030	6,810	7,990	5,850
7	5,960	4,790	6,540	5,400
8	9,320	6,520	7,020	5,900
9	——	——	5,290	4,900
Arithmetical mean	9,102	6,774	6,631	5,203
Standard deviation of a single observation	±1,963	±1,095	±1,449	±738
Coefficient of variability, %	21.6	16.2	21.8	14.2
Av. correction, % of crude roots	25.6		21.5	

The soil was removed from the roots as carefully as possible by washing, the fine roots being caught on a 20-mesh screen. The roots were then dried and weighed. The yields per acre of underground parts, as calculated from the weights of oven-dry crude roots, are given in Table 1 in the columns headed "crude roots."

It is evident that the acre yields varied considerably, even though the square foot samples were selected for their uniformity. It occurred to the junior author that part of the large variation in these samples might be due to incomplete removal of soil from the roots. In order to determine if this were true, the samples were ground, thoroughly mixed, duplicate 5-gram portions ashed in a muffle furnace at low red heat, and the weight of the residue, consisting of soil plus plant ash, determined. The residue was then treated with 50 ml. of 0.2 molar hydrochloric acid, filtered, ignited, and weighed.

Assuming that the acid solution dissolved from the residue an amount of material equivalent to the mineral matter in the roots, the weight of the residue remaining after the acid treatment represented

the soil contained in 5 grams of crude roots. The corrected yields thus obtained are given in Table 1.

In the series A samples, the corrections amounted to 9.4 to 39.3% of the crude roots, the average correction being 25.6%. The range in series B was from 7.4% to 34.5%, the average being 21.5%. The slightly lower average correction in series B was probably due to the more thorough removal of soil permitted by the lesser quantity of roots present.

The importance of the correction is indicated by the smaller standard deviation of the corrected yields as compared to that of the uncorrected yields and by the magnitude of the average correction in terms of percentage of crude roots.

All of the samples collected in 1929 were corrected by this method. The corrections ranged from 8.4% to 42.5% of the crude roots. In only 3 of the 46 samples was the correction below 10%, and 4 were above 30%. The average correction was 18.6%. The standard deviation of a single sample of bluegrass roots, determined from the 46 samples harvested in 1929 distributed in 22 means, was ± 25.0% of the mean before correction and ± 21.5% of the mean after correction for included soil. The standard deviation of the nitrogen content of the roots was ± 13.9% of the mean of the crude samples and ± 13.4% of the mean of the corrected samples. Apparently, the soil in the roots affected the yield more than it affected the composition.

HISTORY OF THE STAND

An area of about 3/4 acre of Miami silt loam was fallowed throughout the summer of 1928. At no time during August or September was there sufficient rain to make a satisfactory seedbed. Finally, the seed was sown in dry soil on September 26 at approximately 110 pounds per acre. The seed was sown from the wheat side of a grain drill with the disks set not to cover, and the area cultipacked. Rains came in October and by the middle of November there was an even, thick stand of bluegrass in the seed-leaf stage only 1/2 to 3/4 inch high.

On March 1 the grass seemed to be entirely dead, but by March 25 it was green and making an excellent start. On March 30, three samples of 1 square foot each were collected. The plants were so small that it was not possible to separate roots and tops and the yields reported in Table 2 under "tops" are actually of the entire plant on that date.

On April 24, part of the area was fertilized with a 10–6–4 fertilizer at the rate of 870 pounds per acre. By the middle of May this fertilized area was quite distinct. By May 24, the grass on the fertilized

TABLE 2.—*Yield and composition of bluegrass, 1929–30, sown Sept. 26, 1928.*

Date of harvest	No. samples	Yield per acre				Nitrogen in			
		Unfertilized		Fertilized		Unfertilized		Fertilized	
		Tops, lbs.	Roots, lbs.	Tops, lbs.	Roots, lbs.	Tops, %	Roots, %	Tops, %	Roots %
				Season of 1929					
March 30	3	280	—	—	—	2.79	—	—	—
April 27	3	510	480	—	—	2.75	3.67	—	—
May 11	3	690	1,220	—	—	2.57	3.06	—	—
May 25	2	2,360	2,110	4,570	1,400	2.28	2.69	3.08	4.27
June 8	2	3,900	2,760	8,170	1,640	1.69	2.34	1.99	3.30
June 21	2	4,010	2,060	8,470	2,120	1.70	2.23	1.81	2.81
July 19 (all samples)	4	—	3,000	—	2,770	—	2.15	—	2.42
July 19, cut June 22	2	2,310	2,770	3,750	2,910	1.78	1.94	1.87	2.20
July 19, not cut	2	6,520	3,240	7,910	2,620	1.76	2.36	1.86	2.64
Aug. 17 (all samples)	3	—	3,680	—	2,740	—	2.05	—	2.41
Aug. 17, cut June 22	2	3,550	4,100	4,570	3,010	1.50	2.04	1.66	2.44
Aug. 17, cut July 23	1	2,360	2,860	2,360	2,200	1.53	2.07	1.71	2.36
Sept. 17 (all samples)	4	—	3,310	—	3,540	—	2.15	—	2.24
Sept. 17, cut June	2	1,600	3,560	2,420	3,430	1.62	2.01	1.55	2.20
Sept. 17, cut July	2	1,950	3,060	2,100	3,650	1.66	2.30	1.70	2.28
Oct. 25 (all samples)	4	—	4,380	—	3,880	—	1.95	—	2.30
Oct. 25, cut June	2	6,270	4,140	7,810	4,550	1.27	1.94	1.40	2.34
Oct. 25, cut July	2	5,960	4,620	5,960	3,220	1.43	1.96	1.52	2.26
				Season of 1930					
April 16	6	3,600	3,680	—	—	—	—	—	—
May 15	4	4,080	4,030	—	—	—	—	—	—
June 11	4	4,060	4,020	—	—	—	—	—	—
July 18	2	1,440	3,170	—	—	—	—	—	—
Sept. 3	2	1,540	3,010	—	—	—	—	—	—
Oct. 4	2	1,850	2,640	—	—	—	—	—	—
Nov. 22	2	3,080	3,430	—	—	—	—	—	—

area ranged from 8 to 12 inches high and was very dense. The unfertilized grass was 4 to 8 inches high. Rootstocks were beginning to appear at this time. There were 2 to 3 times as many rootstocks on the unfertilized part of the plat as on the fertilized part. The samples taken on May 25 indicate that at this time there actually was a greater weight of roots on the unfertilized area than on the fertilized area. Later in the season the amount of roots on the two areas was about the same. The ratio of tops to roots was very different on the two areas, because of the greater weight of tops on the fertilized part.

Another set of samples was taken June 6, when the grass had nearly reached its maximum growth. On June 22 most of the area was mowed, but part of it was left to determine the effect of leaving it uncut. By July 6 this uncut part was a mat of grass leaves 20 to 24 inches long. No seed heads had appeared on the area at any time. This part was finally cut July 23. The sod seemed to be injured by leaving the grass uncut, at least the sod on the part mowed in June was superior to that mowed in July for the rest of the season. The entire area was mowed again on August 19. Samples were taken at monthly intervals through October.

In 1930 samples were taken at intervals throughout the year, but the severe drouth made the yields after June of little importance except as to the extent of the underground parts. There was no increase in the amount of underground parts of bluegrass during 1930; rather the contrary.

The yields and composition of tops and roots from this area are reported in Table 2. In 1929, the individual samples were corrected for included soil by the method just described and the yields reported are all corrected weights. The analyses reported for 1929 have also been corrected for included soil. In 1930, the samples showed so little change because of the dry weather that they were not analyzed. The average correction for included soil of the 1929 samples was applied to the 1930 root samples.

SUMMARY AND CONCLUSIONS

A method was devised for correcting the yields of grass roots for soil which could not be removed by washing. Samples of bluegrass roots which had been washed as thoroughly as possible were shown to contain from 7.4 to 42.5% of included soil.

Although usually considered slow to establish itself, bluegrass sown alone very late in the fall produced by June 8 of the following year a total of 6,660 pounds per acre of roots and tops on an unfertilized

area and of 9,810 pounds on a fertilized area. A sod which would have withstood pasturing was established on the unfertilized area by this time.

The underground parts continued to increase until fall when they averaged about 4,000 pounds to the acre.

At all times, the underground parts contained a higher percentage of nitrogen than the tops. Both the tops and the underground parts from the plats which had received heavy nitrogen fertilization contained a higher percentage of nitrogen than those from the unfertilized area. The difference continued throughout the season, but was much more marked in the underground parts than in the tops, after the first growth had been cut.

Heavy fertilization with nitrogen greatly decreased the relative amount of underground parts. The actual amount of roots in the fertilized area was notably less than in the unfertilized area for a period after the fertilizer was applied, but toward the end of the season the amount of roots was very nearly equal in the two areas.

THE EFFECT OF THE REMOVAL OF TASSELS ON THE YIELD OF CORN[1]

Warren H. Leonard and T. A. Kiesselbach[2]

Yield studies are sometimes made between normal and detasseled plats of corn, especially in natural cross-pollination plats. There has been much conflict in results in regard to the effect of detasseling on the yield of grain. The practise received a great deal of attention in this country between 1890 and 1900, but few tests have been reported since then. The theory at that time was that, with the removal of the tassels, the nutrition of the plant consumed in the production of pollen was diverted in other directions and naturally would be utilized in the production of grain. In opposition to this theory was the possibility of injury to the plant.

It seemed justifiable, under the conditions, to study the problem anew. Such a study was conducted at the Nebraska Experiment Station in 1929.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., Paper No. 124, Journal Series, published with the approval of the Director. Received for publication November 20, 1931.

[2]Formerly Graduate Assistant, Nebraska Agricultural Experiment Station, now Assistant Professor of Agronomy, Colorado Agricultural College, Ft. Collins, Colo., and Agronomist, Nebraska Agricultural Experiment Station, respectively.

HISTORICAL REVIEW

Watson (11),[3] Smith, *et al.* (10), Newman (9), and Gardner (1) show that the yield of corn was increased by removal of tassels. Kimbrough (6) shows that detasseled corn produced an average yield of 68.04 bushels of shelled corn per acre as compared with 67.25 bushels when the tassels were left. Kiesselbach (5) detasseled corn plants for 8 years to determine the effect of their removal on the current crop. As an average, the plats from which the tassels were removed yielded 43.6 bushels per acre as compared with 42.9 bushels for the normal corn. The tassels were pulled out, as they appeared, at the first joint without injury to the leaves.

On the other hand, Hayward (2), Ingersoll (4), and Mills (7) found that the yield was reduced when the tassels were removed. Ingersoll obtained a 25 to 35% reduction in yield from detasseling in 1891, and a reduction of 56.66% in 1892. He concluded that removal of tassels is a positive detriment but failed to give his method. This discrepancy may be due to differences in degree of mutilation of plants by different methods of detasseling.

Still other investigators, like Morrow and Gardner (8), show no effect on yield from tassel removal. Work of Heckel (3) suggests that the composition of the stalk might be considerably influenced by removal of tassels and ears. He showed an increase in sugar content of the stalks, but found variation between different strains of corn in this respect

Indications from the literature are that the removal of tassels would have little or no effect on yield so long as the leaves were uninjured in the process, and ample pollen from other plants provided for.

MATERIALS AND METHODS

The effect of detasseling on the yield of Hogue Yellow Dent corn was studied in 20-hill rows thinned to a 3-plant normal stand. Alternate rows of normal and detasseled plants were compared in 28 replications. The tassels on the rows to be detasseled were pulled out at the first joint or node as they appeared. The field was gone over each day for new tassels.

At the time of harvest, yields were based on all hills containing, and surrounded by, a normal stand.

The acre production was calculated from shrinkage samples for shelled corn containing 14% moisture.

[3]Reference by number is to "Literature Cited," p. 516.

EXPERIMENTAL RESULTS

The results are summarized in Table 1. It will be observed that the normal corn yielded 70.7 bushels per acre while the detasseled corn yielded 71.8 bushels. The chances that a deviation as great as the one found would occur due to chance were once in 1.18 trials. This difference is without statistical significance and may be attributed wholly to random fluctuation.

TABLE 1.—*Effect of the removal of tassels on the yield of corn at Lincoln, Nebr., 1929.*

Description	Replications	Yield of shelled corn per acre	
		Actual, bu.	Relative, %
Normal	29	70.7±0.700	100.0
Detasseled	28	71.8±0.647	101.5
Difference		1.1±0.954	1.5

SUMMARY

An increased grain yield of 1.5% was obtained as a result of detasseling. This difference, however, is not statistically significant and it is concluded that the yield of corn is not materially affected by the removal of tassels when done in such a manner as to avoid mutilation of leaves, and when satisfactory pollination is otherwise provided.

LITERATURE CITED

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THE EFFECT OF POLLEN SOURCE UPON THE GRAIN YIELD OF CORN[1]

T. A. KIESSELBACH and WARREN H. LEONARD[2]

A study was made to determine the immediate effect of fertilization by foreign pollen upon the grain yield of corn (*Zea mays*, L.) when a change either in endosperm type or in heterozygosity is involved. The problem has been attacked from the standpoints of individual plant yield and acre yield. It is an outgrowth of corresponding earlier studies of individual kernel response in the case of ears fertilized with pollen mixtures. Increased kernel weight had been found in such tests to result from pollinations which increased the heterozygosity of the embryo and endosperm and also when a change from sweet to starchy type of endosperm occurred. Because of the possibility that these differences in kernel weight within an ear might merely reflect competition between kernels varying in vigor of growth or in ability to precipitate carbohydrates, it did not seem justifiable to interpret such differences in terms of plant or acre yield effects. To secure direct information on this point, the experiments herein reported were conducted. The results should be of interest in connection with the farm practise of mixing seed of two varieties and also as a study in the technic of field variety tests with this crop.

LITERATURE AND PREVIOUS INDICATIONS

The literature bearing on this problem has been rather fully reviewed by Kiesselbach[3] in a bibliography of 10 papers.

The experimental data heretofore reported by various workers have been concerned largely with the comparative weights of pure and hybrid kernels occurring on the same corn ear. The general indications from such earlier work may be summarized as follows:

1. In case kernels of similar endosperm type differ in heterozygosity due to differential pollination, a positive correlation with increased kernel weight may be expected. Both embryo and endosperm are likely to be affected in the same direction. The most striking effects occur with crossed kernels in selfed lines and single F_1 hybrids and with selfed kernels in open-pollinated varieties.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Paper No. 123, Journal Series, published with the approval of the Director. Received for publication November 20, 1931.

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[3]KIESSELBACH, T. A. The immediate effect of gametic relationship and of parental type upon the kernel weight of corn. Nebr. Agr. Exp. Sta. Res. Bul. 33. 1926.

2. The immediate effect of crossing on kernel weight is but very slight when two heterozygous varieties of similar endosperm type are involved, and in such case maximum effect may be expected when the two varieties differ greatly in vegetative type with respect to earliness of maturity and vegetative size. This effect may then perhaps be regarded as size inheritance. Diminutive type of the male may tend to depress kernel weight slightly, and vice versa.

3. When sweet corn is pollinated with a mixture of pollen from sweet and starchy varieties, the endosperm weight is greatly increased by the starchy pollen. This is evidently due to increased enzymatic activity in the resultant starchy kernels, accompanied by a more rapid precipitation of sugars in the form of starch during kernel development. This serves to lower the osmotic pressure within the hybrid kernels and the outcome is a greater translocation of solutes from the vegetative parts to those kernels which were fertilized by the starchy variety. That this increased kernel weight is not due to a material change in heterozygosity is evident from the failure of the embryo to respond materially in weight to the cross fertilization.

4. No data appear available in the literature indicating to what extent the total yield of grain per plant or per acre may be influenced in the current crop by the genetic constitution of the pollen.

METHODS

STRAINS AND VARIETIES USED

The corn employed to develop the principles in question has consisted of an open-pollinated variety of sweet corn (Stowell's Evergreen), a selfed line of Hogue Yellow Dent (Nebr. No. 12), and an F_1 single cross between two Hogue Yellow Dent selfed lines (Nebr. No. 2 x 12).

In other tests in which these various sorts had each been fertilized by mixtures of their own and unrelated dent pollen, the excess kernel weights due to crossing were as follows: Sweet corn, 22%; Nebr. No. 12, 16%; and Nebr. F_1 2 x 12, 8%.

MANNER OF TESTING

All tests were made under field conditions on the Experiment Station farm at Lincoln. The procedure was to contrast the yields of cross-pollinated individual plants and replicated 30-hill plats with comparable plants or plats which were supplied solely with pollen of their own kind. The tests with the selfed lines and the hybrid were limited to individual plant yield comparisons, while those with sweet corn were made by both the plant and plat methods.

Plant yield tests.—The individual plant yield studies involved hand pollination. The corn was planted in hills, four kernels per hill, and the stand later thinned to two plants. Suckers were removed in their

early development. Nebraska White Prize, which was used as the foreign pollen parent, was planted in nearby blocks at three different dates to insure an ample supply of foreign pollen. In each hill one of the plants was sib-pollinated while the other was pollinated by unrelated pollen.

Position of the plants used for each kind of pollination was reversed in successive hills in order to avoid any systematic error due to position. To secure reliable results it was necessary to approximate perfect pollination. A pollen-gun, such as has been described by M. T. Jenkins, was found to be the most satisfactory device where mass pollinations were required. In the use of this equipment, the ear shoots and tassels were bagged as in the ordinary sack method of control pollination. The plants were each pollinated three times at two-day intervals. For yield determinations all plants were used whose ears showed a 90% kernel fill or better. In this way two groups of ears, pure and hybrid, were harvested whose moisture-free yields of shelled corn per plant were determined.

Acre-yield tests.—In the acre-yield tests, all seed was hand planted in hills, six kernels per hill, and the young plants later thinned to three per hill. Two isolated, natural crossing fields were used in which the source of pollen could be controlled. Stowell's Evergreen Sweet and Hogue Yellow Dent corn were planted in alternate rows in each isolated field. In one field, all sweet corn tassels were removed as they appeared so that all plants of both varieties would be fertilized by dent corn pollen, while in the other field all dent corn tassels were removed.

The above pollinations permitted determination of relative grain yields in one field of alternating sweet corn and dent corn plats fertilized exclusively by dent corn pollen and, in the other field, of alternating rows of sweet corn and dent corn fertilized entirely by sweet corn. The difference in relative yields of the dent and sweet corn as determined in the two different fields may be attributed to the differential effects of the two kinds of pollen on the sweet variety. The dent corn may be used as a basis for comparison in both fields because, as has been shown by Kiesselbach,[4] the kernels of dent corn weigh essentially alike whether fertilized by pollen from dent or sweet varieties. The endosperms are starchy in either case.

For the calculation of comparative yields, only hills containing three plants and surrounded by a normal stand were harvested. The acre yields are on the basis of shelled corn containing 14% moisture.

The detasseling in these experiments may be regarded as introduc-

[4] *Loc. cit.*

ing no important systematic error. Tests by the authors[5] and by others have indicated negligible effects upon grain yield from pulling tassels if care is taken to avoid loss of leaves in the process.

RESULTS WITH SWEET CORN

ACRE YIELDS

The data concerning the effects upon the acre yield of sweet corn from fertilization by pollen carrying the starchy factor are given in Table 1. Since a direct comparison of the sweet corn yields under the

TABLE 1.—*Comparative acre yields of Hogue Yellow Dent and Stowell's Evergreen Sweet corn when pollinated respectively by dent and sweet varieties at Lincoln, Nebr.*

Type of corn involved		Replications	Yield shelled corn per acre (14% moisture content)	
Female	Male		Actual, bu.*	Relative, %
		Field A		
Dent	Dent	27	75.3±0.70	100
Sweet	Dent	26	38.2±0.68	51
		Field B		
Dent	Sweet	23	74.9±1.31	100
Sweet	Sweet	23	28.4±1.03	38

*The probable errors of all mean yields reported in this paper have been calculated by Bessel's formula.

two conditions of pollination is impossible due to the natural crossing plats being in different fields, these relative yields must be established indirectly through comparison with the dent corn as a common check. The dent corn may serve this purpose without material error for it has been shown in earlier tests that the weight of dent corn kernels is but slightly affected by the kind of pollen applied.

The sweet corn pollinated by sweet corn yielded 38% as much as the dent corn, and when pollinated by dent corn it yielded 51% as much as the dent variety. From this relationship the ratio of 38:51 as 100:X may be established. This points to a 34% increase in the acre yield of the sweet corn resulting from the transformation of the sweet to a starchy endosperm.

INDIVIDUAL PLANT YIELDS

The grain yields of individual sweet corn plants pollinated by sweet and dent pollen, respectively, are summarized in Table 2.

The average difference in individual plant yields for the two groups was found to be 13.7 ± 1.99 grams in favor of the plants pollinated

[5]LEONARD, WARREN H., and KIESSELBACH, T. A. The effect of the removal of tassels on the yield of corn. Jour. Amer. Soc. Agron., 24:514-516. 1932.

TABLE 2.—*Comparative grain yields of sweet corn plants pollinated respectively with sweet corn and dent corn pollen at Lincoln, Nebr.*

Types of corn involved		Number of plants	Mean weight shelled corn per plant	
Female	Male		Actual, grams	Relative, %
Sweet	Sweet	124	109.2±1.14	100
Sweet	Dent	76	122.9±1.64	113
Difference			13.7±1.99	13

with foreign dent pollen. The chances that a deviation as great as the one found would occur due to chance is once in 434,783 trials. Calculated on a percentage basis, the sweet corn yielded 13% more when pollinated by dent pollen than when its own pollen was used.

RESULTS WITH A SELFED LINE

In the case of selfed line No. 12, the effect of foreign pollen upon grain yield was determined only by the individual plant yield method. The results are given in Table 3.

TABLE 3.—*Comparative grain yields of plants within a selfed line (Nebr. No. 12) when pollinated respectively with their own and foreign dent pollen at Lincoln, Nebr.*

Types of corn involved		Number of plants	Mean weight shelled corn per plant	
Female	Male		Actual, grams	Relative, %
Nebr. No. 12	Nebr. No. 12	79	99.9±1.21	100
Nebr. No. 12	White Prize	90	102.1±1.47	102.2
Difference			2.2±1.9	2.2

For this selfed line a difference of 2.2% in the yield of grain was obtained in favor of the plants fertilized by unrelated pollen. With the difference but slightly greater than its probable error it would appear wholly within the limits of experimental error.

TABLE 4.—*Comparative grain yields of plants within an F_1 single cross (Nebr. 2 x 12) when pollinated respectively with their own and foreign dent pollen at Lincoln, Nebr.*

Types of corn involved		Number of plants	Mean weight shelled corn per plant	
Female	Male		Actual, grams	Relative, %
Nebr. 2 x 12	Nebr. 2 x 12	59	152.8±2.14	100
Nebr. 2 x 12	White Prize	44	152.6±2.52	100
Difference			0.2±3.30	0.0

RESULTS WITH A FIRST GENERATION HYBRID

The effects of pollen source upon the grain yields of individual first-generation, single-cross plants are reported in Table 4.

The difference of 0.2 ± 3.3 gram in the mean yields of plants pollinated by sib-pollen and plants pollinated by foreign pollen is clearly insignificant.

DISCUSSIONS AND CONCLUSIONS

As an average for two experiments with sweet corn the immediate effect of cross fertilization with dent corn pollen was a 24% increase in grain yield. In comparison, hybrid starchy kernels on individual ears fertilized with pollen mixtures weighed 22% heavier than pure sweet kernels. Since the sweet corn was of normal heterozygous constitution, the increased grain yield is attributed to a change from sweet to starchy endosperm. It is suggested that a more complete translocation of elaborated materials from the vegetative parts to the grain, made possible by the change of endosperm type, may account for the greater grain yield Such a result should be accompanied by a lowering of stalk weight, although no test was made of this relationship

The failure of both the selfed line and the F_1 single cross to increase significantly in grain yield per plant when cross pollinated suggests that the grain yields of plants are not materially affected by differences in the heterozygosity of their grain as influenced by the pollen. Individual kernels of the selfed line and hybrid used in this test had previously responded to cross fertilization by the respective increases of 16 and 8%, when both pure and hybrid kernels were located on the same ear.

This failure to increase in grain yield per plant would seem to indicate that the amount of materials elaborated and translocated by the corn plant is not materially affected by pollen source when a change in endosperm type is not involved. It appears from these data that there is some competition effect when the pure and hybrid kernels are on the same ear and that the cross-pollinated kernels grow larger at the expense of adjacent pure kernels. A corresponding effect on plant yields does not occur, probably because the total food material supplied to the plant is the same whether its kernels are pure or hybrid.

Accordingly, it is concluded that the cross pollination which naturally occurs in comparative tests of varieties, selfed lines, or hybrids does not materially modify the total yield of grain when there is no accompanying change in endosperm type. On the other hand.

the grain yield of sweet corn plants is enhanced by fertilization with pollen carrying the starchy endosperm factor.

Reliable comparative yields of sweet and starchy varieties cannot be established under conditions where the sweet corn is subject to pollination by the starchy varieties. Inter-pollination among dent or other starchy varieties, selfed lines, and hybrids seems permissible in variety tests with the result that no material yield effects will occur.

No increase in grain yield is to be expected as an immediate effect of cross fertilization in connection with the practise of annually mixing seed of two or more corn varieties.

METHODS OF TESTING INBRED LINES OF MAIZE IN CROSSBRED COMBINATIONS[1]

Merle T. Jenkins and Arthur M. Brunson[2]

In testing inbred lines of corn, it has been the custom of many corn breeders to combine systematically the lines to be compared in a series of comparable crosses Although the performance of the individual crosses is determined, the inbred line usually is saved or discarded on the basis of the mean of all of its crosses. This necessitates making and testing very large numbers of crosses.

In order to determine the feasibility of a less arduous method of testing inbred lines in crosses, comparisons of different methods of testing inbred lines were made in 1929 and 1930 at the Iowa Agricultural Experiment Station and in 1930 at the Kansas Agricultural Experiment Station. The results are presented in the present paper.

MATERIAL AND METHODS

The material on which this study is based may be arranged conveniently into five groups, as described below

GROUP I

This group comprised 37 inbred lines which had been tested in series of nine comparable single crosses in Iowa in 1927, the crosses having been made after four generations of inbreeding. In 1928,

[1]The data on which this paper is based were obtained in connection with the corn breeding programs conducted by the Iowa and Kansas Agricultural Experiment Stations in cooperation with the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Journal Paper No. B19 of the Iowa Agricultural Experiment Station and Contribution No. 213, Department of Agronomy, Kansas Agricultural Experiment Station. Received for publication December 3, 1931.

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remnant seed from these fourth generation selfed ears was planted and the plants detasseled and wind pollinated with pollen from a varietal mixture. The varietal mixture was made up by mixing equal quantities of seed of 25 strains of open-pollinated corn suited to south central Iowa and requiring about an equal period to reach maturity. These "inbred-variety crosses,"[3] with the varietal mixture, were compared in 1929 and their performance correlated with the mean performance of the single crosses of the same parent lines grown in 1927.

GROUP 2

This group comprised 12 early- and 17 late-maturing lines of yellow corn inbred for six generations and first used in crosses in Iowa in 1928. The 12 early-maturing lines were compared in series of nine comparable single crosses with the early-maturing lines of yellow corn mentioned below in Group 4. The 17 late-maturing lines were compared in series of 10 comparable crosses with the late-maturing lines of yellow corn mentioned in Group 4.

These lines were included in the crossing plat with those of Group 1 and the plants detasseled and wind pollinated with pollen from the varietal mixture. The crosses were compared in 1929.

GROUP 3

This group of Iowa inbreds comprised four sub-groups, *viz.*, (1) 11 early-maturing lines of white corn, (2) 17 early-maturing lines of yellow corn, (3) 10 late-maturing lines of Reid Yellow Dent type, and (4) 10 late-maturing lines of Lancaster Surecrop. The lines of each sub-group were compared in series of 10 comparable single crosses. The lines of each sub-group also were crossed with a commercial variety, the inbred line being used as the pistillate parent in each case. The white lines were crossed with Four County White, the early-maturing yellow lines with Bige Yellow Dent, and the two groups of late-maturing lines with Krug. The crosses were compared in 1930.

GROUP 4

This group comprised three sub-groups, *viz.*, (1) 9 early-maturing lines of white corn, (2) 9 early-maturing lines of yellow corn, and (3) 10 late-maturing lines of yellow corn. All of the lines had been inbred at Ames for six generations, with the exception of one of the lines of white corn which had been inbred for five generations.

[3]The expression "inbred-variety cross" is used to designate the crosses of inbred lines with open-pollinated commercial varieties, regardless of whether the inbred line was the staminate or pistilate parent.

Each sub-group was used in 1928 in two comparable series of single crosses. All possible combinations were made among the lines of each sub-group. In addition, the 9 lines of white corn were crossed with each of 13 other lines of white corn, the 9 early-maturing lines of yellow corn were crossed with the 12 early-maturing lines of yellow corn of Group 2, and the 10 late-maturing lines of yellow corn were crossed with the 17 late-maturing lines of yellow corn of Group 2.

With few exceptions, all of these combinations were obtained. They were compared in 1929.

The methods of making the crosses and of conducting the yield comparisons were identical in all essential details to those already described.[4] Data were taken on a number of different characters which are indicated in sufficient detail in the different tables.

GROUP 5

This group consisted of 60 lines of Pride of Saline inbred at the Kansas Station for three generations. These lines were divided into six groups of 10 lines each and single crosses were made between each line of the odd groups and each of the 10 lines of the next higher group. Sufficient seed for planting all 10 crosses was not obtained in some cases so that frequently the averages for an individual line are based on less than 10 crosses. The same 60 lines were planted in an open-pollinated field of the parent variety, Pride of Saline, and detasseled to produce the inbred-variety crosses. The inbred-variety cross was not obtained for one line so that the correlations are based on 59 pairs of observations in each case. The single crosses and the inbred-variety crosses were grown in triplicate series in 1930.

EXPERIMENTAL RESULTS

The coefficients of correlation between the mean values of the single crosses of the tested lines and the corresponding values of the inbred-variety crosses of these lines are recorded in Table 1. For convenience in judging the significance of these coefficients, "significant r" values, corresponding to $P = 0.05$, are included at the bottom of each column. These significant r's are from Fisher's Table V. A.[5]

In Table 1 the correlations for Group 1 differ from those of the other three groups in that the single crosses and the inbred-variety

[4]Jenkins, Merle T. Correlation studies with inbred and crossbred strains of maize. Jour. Agr. Res., 39:677–721. 1929.

[5]Fisher, R. A. Statistical methods for research workers. London: Oliver & Boyd. Ed. 3. 1930.

TABLE 1.—*Coefficients of correlation for the mean values of characters in crosses of inbred lines with a series of other inbred lines and the values of the same characters in crosses of the inbred lines with open-pollinated varieties.*

Characters	Coefficients of correlation										
	Group 1	Group 2			Group 3					Combined coefficients for groups 2 and 3	Group 5
		12 early yellow lines	17 late yellow lines	All 29 lines	11 early white lines	17 early yellow lines	10 late yellow lines	10 Lancaster lines	All 48 lines		
Date ¼ tasseled	0.69	0.46	0.67	0.64	—	—	—	—	—	—	0.98
Date ¼ silked	0.70	0.39	0.71	0.65	—	—	—	—	—	—	—
Date of maturity	—	—	—	—	—	—	—	—	—	—	0.96
Moisture at harvest, %	0.69	0.62	0.82	0.76	0.90	0.69	0.82	0.92	0.82	0.80	—
Plants with burned leaves, %	—	—	—	—	0.91	0.74	0.88	0.89	0.82	—	—
Plants with burned tassels, %	—	—	—	—	0.80	0.73	0.96	0.73	0.81	—	—
Plant height	0.34	0.65	0.01	0.31	0.69	0.65	0.49	0.71	0.63	0.52	—
Ear height	—	0.79	0.79	0.78	0.58	0.48	0.56	0.87	0.61	0.71	—
Plants erect, %	0.54	0.90	0.90	0.90	0.93	0.89	0.86	0.84	0.88	0.88	0.59
Plants smutted, %	—	0.82	0.66	0.72	0.69	0.69	0.09	0.73	0.67	0.61	0.65
Stalks per plant	—	0.80	0.83	0.82	0.80	0.37	0.89	0.80	0.68	0.74	0.72
Ears per plant	—	0.52	0.54	0.53	—	—	—	—	—	—	0.57
Ears per cwt	0.65	0.33	0.75	0.59	0.54	0.64	0.72	0.76	0.64	0.63	—
Ear length	—	0.92	0.81	0.88	—	—	—	—	—	—	—
Shelling %	0.78	0.85	0.77	0.80	0.88	0.87	0.87	0.95	0.90	0.86	—
Test weight per bu	—	—	—	—	0.77	0.77	0.78	0.93	0.78	—	—
Acre yield	0.53	0.80	0.65	0.68	0.90	0.86	0.63	0.90	0.83	0.75	0.56
Significant *r*	0.32	0.58	0.48	0.38	0.60	0.48	0.63	0.63	0.30	0.24	0.26

crosses were grown in different seasons. It might be expected that the characters subject to environmental influence would show less correlation than had they been grown in the same season. All of the correlations in this group, however, may be considered significant. The lowest correlation was for plant height and the largest for shelling percentage. The correlation for acre yield was 0.53.

Nine of the 13 correlations for the 12 early-maturing lines of Group 2, all but 1 of the 13 correlations for the 17 late-maturing lines of this group, and all but 1 of the correlations for the early and late lines combined are significant. Plant height had the lowest combined correlation and, in this case, percentage of plants erect had the highest correlation (0.90) The correlations for acre yield were 0.80 for the early lines, 0.65 for the late lines, and 0.68 for the early and late lines combined.

The correlations in Group 3 are slightly higher than those for either Groups 1 or 2. All but four of them are significant. This material was compared in the extremely dry and unfavorable season of 1930. There was much more than the usual variability among crosses of different parent lines during this season. This may account in part for the higher correlations in Group 3. Another difference between Group 3 and Groups 1 and 2 was that the inbred-variety crosses in Group 3 were with individual commercial varieties whereas those of Groups 1 and 2 were with a varietal mixture. Among the combined correlations for the 48 lines in this group that for shelling percentage was largest and that for ear height was smallest. The combined coefficient for acre yield was 0.83.

Combined coefficients of correlation were computed for Groups 2 and 3, which include 77 lines. Group 1 was not included as it represented comparisons in different seasons. The largest of the combined correlations was for percentage of plants erect and the smallest for plant height. The combined correlation for acre yield was 0.75. All of the combined coefficients are highly significant.

The correlations in Group 5 may best be compared with the combined correlations of Groups 2 and 3. Among four direct comparisons, three of the correlations in the Iowa material are the larger. The fact that the Kansas lines had been inbred for only three generations when crossed may partially account for these lower correlations. The correlations in the Kansas material which indicate the relative length of season required to mature (date ¼ tasseled and date of maturity) are much larger than any of the Iowa correlations indicating relative maturity (date ¼ tasseled, date ¼ silked, and percentage of moisture at harvest). It is possible that the high

variability of Pride of Saline and the wide range of derived inbred lines with respect to length of growing season may explain, in part, these high correlations. The correlations for acre yield were 0.56 in the Kansas material and 0.75 in the Iowa material.

The correlations in Table 1 were obtained by pairing the mean performance of a number of single crosses, on the one hand, with the performance of an individual inbred-variety cross, on the other hand. In the correlations in Group 4 (Table 2) the mean performances of inbred lines in two different series of single crosses were paired. These correlations, therefore, measure the similarity of performance to be expected between different tests of inbred lines with a series of other inbred lines. They may be used as a standard with which to compare the correlations between the mean performance of crosses with inbred lines and the performance of the inbred-variety crosses. In this manner the efficiency of the inbred-variety crosses in estimating the value of inbred parent lines may be determined.

TABLE 2.—*Coefficients of correlation between the mean values of characters in crosses of inbred lines tested in two series of crosses with other inbred lines.*

Characters	Coefficients of correlation			
	9 early white lines	9 early yellow lines	10 late yellow lines	All 28 lines
Date ¼ tasseled	0.76	0.98	0.95	0.88
Date ¼ silked	0.77	0.96	0.86	0.86
Moisture at harvest, %	0.98	0.94	0.95	0.95
Plant height	0.85	0.93	0.91	0.88
Ear height	0.92	0.97	0.98	0.97
Plants erect, %	0.98	0.94	0.92	0.93
Plants smutted, %	0.30	0.97	0.96	0.79
Stalks per plant	0.45	0.85	0.85	0.50
Ears per plant	0.66	0.67	0.74	0.68
Ears per cwt.	0.87	0.86	0.42	0.78
Ear length	0.98	0.97	0.92	0.95
Shelling %	0.50	0.90	0.73	0.76
Acre yield	0.82	0.69	0.65	0.71
Significant *r*	0.67	0.67	0.63	0.41

Most of the combined coefficients of correlation in Table 2 are higher than those for the groups in Table 1. The outstanding exception is the correlation for shelling percentage which is lower than the similar correlations in any of the other groups. The combined correlation for acre yield in Table 2 (0.71) is slightly lower than the similar correlation for Groups 2 and 3 (0.83) and considerably higher than that for Group 5 (0.56).

DISCUSSION

In a previous publication,[6] the objects of testing inbred lines in crosses are discussed. It was concluded that if the lines are to be used in double crosses, multiple crosses, or synthetic varieties, the most valuable lines are those which cross well with a large number of inbred lines or, in other words, those which, on the average, produce the best hybrids when tested with a rather wide range of germ plasm. It seemed desirable to determine whether this wide range of germ plasm might not be supplied in one cross with a varietal mixture, or possibly in a cross with an individual variety. From the data which have been presented it would seem that this might be done.

TABLE 3.—*Summary of the coefficients of correlation for moisture percentage, erect plants, and acre yield.*

Character	Coefficients of correlation		
	Groups 2 and 3	Group 5	Group 4
Moisture, %	0.80	0.96*	0.95
Plants erect, %	0.88	0.59	0.93
Acre yield	0.75	0.56	0.71
Significant r	0.24	0.26	0.41

*Coefficient for moisture percentage was not computed for this material and so the coefficient for date of maturity is substituted.

There are, of course, many things which influence the final selection of inbred parent lines on the basis of their performance in crosses. Perhaps the three items to which greatest emphasis usually is given are (1) acre yield, (2) percentage of plants erect at harvest, and (3) moisture content of the harvested ears. The coefficients of correlation for these three characters in the different groups of material are worthy of more detailed consideration. Those for Groups 2 and 3 combined and for Groups 4 and 5 are shown in Table 3 for more ready comparison.

Taking the correlations of Group 4 as a standard, the combined correlations for Groups 2 and 3 compare extremely favorably with them. They are sufficiently alike so that the use of inbred-variety crosses would seem to be of real promise in predicting the mean performance of these lines in a series of single crosses.

The correlations in the Kansas material for percentage of plants erect and acre yield are somewhat lower than the corresponding coefficients in Group 4. It is regretted that correlations between the

[6]See footnote 4.

means of crosses for two series of single crosses under Kansas conditions are not available for comparison. These correlations in the Kansas material are highly significant, however, and it is felt that they are large enough to make the method of testing with inbred-variety crosses a usable one.

SUGGESTED PROCEDURE

On the basis of the data presented in this paper it is suggested that crosses of inbred lines with a commercial variety may well be used for the rapid, preliminary testing of new lines. These crosses can be economically made in an isolated crossing plat in which the variety is used as the pollen parent.

The selection of the variety for crossing will depend upon the use to which the new lines are to be put. They may be crossed with the parent variety from which they were developed. Or, if the new lines are intended for crossing with lines of another variety, they may be crossed with that variety. It is possible, also, that as the corn breeding work progresses and several desirable lines are isolated, that the most desirable new lines developed will be the ones which combine best with the established lines. In such a case it may be possible to combine the established lines into a double cross, double-double cross, or multiple cross of some sort which may be used in a similar manner for crossing with new lines.

The writers believe that on the basis of performance of the tested lines in these crosses with varieties it should be possible to eliminate 50% of the lines without danger of losing any really superior material. The remaining 50% may be given a more careful test in combination with individual inbred lines.

SUMMARY

Coefficients of correlation for a number of different characters were determined between the mean performance of the single crosses of inbred lines of corn and the performance of these lines in crosses with a commercial variety or with a varietal mixture.

Coefficients of correlation also were determined between the mean performance of the crosses of several inbred lines used in two series of crosses.

From a comparison of these correlations it is concluded that crosses with open-pollinated varieties may be used efficiently in the preliminary testing of new lines.

CYTOLOGICAL ABERRATIONS IN RELATION TO WHEAT IMPROVEMENT[1]

LeRoy Powers[2]

Crop investigators have realized for some time that considerable inherited variability is encountered within a single variety of wheat. Some varieties are known to be less uniform in type than others. Natural crossing and mechanical mixtures no doubt play an important part. Later investigations have shown that in some cases cytological aberrations are associated with variability. Huskins (3)[3] explains the occurrence of speltoids in wheat varieties as being due to chromosomal aberrations. Powers (4) has found that certain cytological aberrations occurring during microsporogenesis of parent plants of Marquillo are associated with variability within the offspring. Cytological aberrations have been reported as occurring in other varieties of wheat by Sapehin (5), Hollingshead (2), and Powers (4). It is of importance to the breeder to determine the extent of variation in the occurrence of cytological aberrations within varieties, the possibility of using the frequency of occurrence of any one aberration as a criterion of the others, the relationship between these aberrations and field characters, and the possibilities of reducing the amount of cytological aberrations. It is believed that the studies reported here aid in the solution of these problems.

MATERIAL AND METHODS

Marquillo, Marquis, and Minn. No. 2303 were the varieties used in this investigation. Some of the results previously reported (4) for Marquillo have been summarized for comparison with those obtained in the studies with Marquis and Minn. No. 2303. Marquillo and Minn. No. 2303 were obtained from the wheat breeding studies conducted cooperatively by the Minnesota Experiment Station and the U. S. Dept. of Agriculture. Marquillo is a selection from a cross made in 1914 between Marquis, a common bread wheat, and Iumillo, a durum wheat. It is resistant to black stem rust, of desirable agronomic type, but is somewhat inferior in color of loaf, although this can be controlled by bleaching. Marquis is a selection from a cross

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[3]Reference by number is to "Literature Cited," p. 536.

of two vulgare varieties made by A. P. Saunders, probably at the Agassiz Experiment Station in Canada, in 1892. Minn. No. 2303 resulted from a cross made in 1921 between a sister selection of Marquillo with a selection from a Kanred x Marquis cross. It combines field resistance to many and perhaps all physiologic forms of black stem rust with immunity to 11 forms. It is of desirable agronomic type and appears to be superior in milling and baking quality.

The methods employed were essentially the same as those reported in a previous article (4) and for that reason are not given in detail here. In brief, the study consisted of a determination of the frequency of three types of chromosomal irregularities of parent plants of the three varieties. Progenies of these plants were then grown the following year and statistical measures obtained for weight of seed produced, height of plant, and fruitfulness of the outside rows of florets. The data were summarized on a plant basis and the means and coefficients of variability for each character in the progeny lines were then correlated with the frequency of cytological irregularities of the parent plants. All plants, whether studied cytologically or for plant characters, were grown in rows 1 foot apart with the plants spaced 3 inches within the row. Thirty-two plants of Marquillo, 27 of Marquis, and 25 of Minn. No. 2303 were studied for cytological aberrations. Of the progeny grown the following number of lines of each variety were used in the correlation studies: Marquillo 23, and Marquis and Minn. No. 2303, 25 each. The plants of Marquillo studied cytologically were grown in 1929 and the progeny of these plants in 1930, whereas the Marquis and Minn. No. 2303 plants studied cytologically were grown in 1930 and the progeny in 1931. Fisher's (1) tables were used in determining the reliability of the correlation coefficients obtained. All cytologic studies were made from permanent paraffin sections stained by Newton's iodin-gentian violet method as described by Huskins.

Before giving the experimental results it might be well to consider the terminology used in describing the different chromosomal aberrations. Illustrations of these phenomena are given in a previous publication (4). Micronuclei is the term employed to describe the occurrence of darkly staining chromatin material in the cytoplasm of the immature pollen grains. Non-orientation is the term applied to the failure of a pair or pairs of chromosomes to line up on the equatorial plane during metaphase of the first division of the pollen mother cells. Non-conjunction is the term applied to the occurrence of single chromosomes at the metaphase stage of the first division of the pollen mother cells.

EXPERIMENTAL RESULTS

Table 1 gives the percentage frequency of the different chromosomal aberrations found occurring in the three varieties studied.

TABLE 1.—*Average percentage of different chromosomal aberrations of individual plants of three varieties of wheat found occurring during formation of the pollen grains.*

Aberration	Marquillo	Marquis	Minn. No. 2303
Micronuclei	2.8±.16	0.8±.06	0.8±.05
Non-orientation	10.8±.68	6.9±.49	6.8±.38
Non-conjunction	6.1±.44	7.7±.93	3.4±.27

Marquillo averaged significantly higher in the percentage of immature pollen grains showing micronuclei and the percentage of pollen mother cells showing non-orientation. Marquillo and Marquis did not differ significantly in the percentage of non-conjunction. Marquis and Minn. No. 2303 did not differ significantly in the percentage of micronuclei or non-orientation, but Marquis averaged significantly higher in the percentage of non-conjunction. These results show that cytological aberrations occur in greater frequency in Marquillo than in Marquis and Minn. No. 2303. Also, they show Minn. No. 2303 to be as free, if not freer, from these aberrations than Marquis.

The relationship existing between the different aberrations is shown by the coefficients of correlation listed in Table 2.

TABLE 2.—*Coefficients of correlation between percentage frequencies of different chromosomal aberrations of individual plants of three varieties of wheat.**

Aberrations correlated	Correlation		
	Marquillo	Marquis	Minn. No. 2303
Micronuclei and non-orientation	+.70	+.70	+.11
Micronuclei and non-conjunction	+.32	+.17	−.18
Non-orientation and non-conjunction	+.12	+.12	+.06

*Levels of significance: According to Fisher's (1) tables for the value of the correlation coefficient for different levels of significance an N of 20 and r of .42 gives a P value of .05.

In Marquillo and Marquis, the association of percentage micronuclei was high, the coefficient of correlation being + .70 in each variety. The same relationship was positive in Minn. No. 2303 but was not statistically significant. In Marquillo and Marquis the occurrence of micronuclei was positively correlated with non-conjunction, the coefficients of correlation being + .32 and + .17, re-

spectively. Coefficients of correlation of .42 would have been significant according to Fisher's (1) tables. The correlation coefficients between micronuclei and non-conjunction were positive for all three varieties, although not statistically significant.

From the standpoint of wheat improvement, these aberrations are of importance only in so far as they measure genotypic variations. If they are measures of germinal instability, they should be positively correlated with the variability of the offspring of the plants in which

TABLE 3.—*Coefficients of correlation between the frequency of three types of chromosomal aberrations of parent plants and coefficients of variability and means of the progeny for three plant characters.**

Characters and aberrations correlated	Correlation					
	Marquillo		Marquis		Minn. No. 2303	
	C.V.	Mean	C.V.	Mean	C.V.	Mean
Weight of seed and						
Micronuclei	+.51	—.38	+.08	—.56	+.18	—.07
Non-orientation	+.33	—.11	+.16	—.61	—.51	+.05
Non-conjunction	+.45	—.34	+.02	—.08	—.09	+.07
Height of plant and						
Micronuclei	+.47	—.19	+.08	—.39	+.29	—.01
Non-orientation	+.53	—.25	+.22	—.31	—.19	+.10
Non-conjunction	+.11	—.38	—.22	+.06	—.17	—.15
Fruitfulness and						
Micronuclei	+.61	—.48	+.23	—.39	+.06	—.01
Non-orientation	+.49	—.42	+.29	—.58	—.20	+.28
Non-conjunction	+.27	—.35	+.21	—.32	—.31	+.51

*Levels of significance: According to Fisher's (1) tables for the value of the correlation coefficient for different levels of significance an N of 20 and an r of .42 gives a P value of .05.

they occur. The coefficient of variability was used as a measure of variability and was calculated for the following characters of the progeny of all three varieties: Weight of seed of each plant expressed in grams, height of each plant taken in inches, and percentage fruitfulness of each plant. The coefficients of correlation obtained are shown in Table 3.

Two types of correlation coefficients were used in the study of relationship between cytological aberrations and plant characters, one in which the percentage frequency of the three different aberrations was correlated respectively with the coefficients of variability of weight of seed per plant, height per plant in inches, and percentage fruitfulness; and the other in which the same three measures of cytological irregularities were correlated with the means of the three characters studied in the progeny. For Marquillo there was a positive

correlation between the percentage frequency of the three types of cytological irregularities and the coefficients of variability for weight of seed, height of plant, and fruitfulness of the progeny. A considerable percentage of these correlation coefficients were probably statistically significant. With Marquis and Minn. No. 2303 the correlation coefficients calculated for these same relationships appeared for the most part to have no statistical importance. The fact that all correlations, with the exception of one, were positive with the Marquis variety indicates the possibility of a significant relationship. In the studies of the relationship between the cytological irregularities of the parent plants and the means for the three characters studied in the progeny, there is some reason to conclude that the cytological irregularities have an important relation to the development of these characters in Marquillo and Marquis. With the exception of the relationship between non-orientation and weight of seed, none of the correlations between cytological aberrations and characters of Minn. No. 2303 plants were statistically significant. In the exceptional case a negative, rather than a positive, correlation was obtained. This is not what would be expected on the basis of the results with Marquillo and Marquis, nor is this correlation substantiated by the other data for this variety. Therefore no significance is attached to it.

DISCUSSION AND SUMMARY

Cytological irregularities were found to be occurring in all three of the varieties studied and no plants failed to show at least a small percentage of cytological aberrations during maturation of their pollen mother cells. As measured by cytological aberrations, Marquillo was found to be more unstable than either Marquis or Minn. No. 2303, whereas Marquis and Minn. No. 2303 were about equal in this respect, although Minn. No. 2303 gave a lower percentage of non-conjunction. Since Minn. No. 2303 is the result of an attempt to combine the desirable characters of the durum and vulgare groups of wheat and therefore shows, as far as practical purposes are concerned, that a germinally stable variety can be obtained from crosses involving these two species, it is of special interest to the agronomist and plant breeder.

The correlations found to exist between the different aberrations strongly indicate that the occurrence of micronuclei may be taken as a criterion of the frequency of occurrence of non-orientation and non-conjunction. If such proved to be the case, the work and time involved in determining the germinal instability of a variety or cross

may be greatly reduced, and, consequently, the number of plants that can be studied materially increased. It is comparatively easy to find the tetrad stage of microsporogenesis at which time the percentage of cells showing micronuclei are determined, but it is rather difficult to find the proper stage for determining the percentage of pollen mother cells that exhibit non-orientation and non-conjunction.

The cytological aberrations in the parent plants of Marquillo were found to be positively associated with variability of some characters of the progeny. These aberrations were also found to be negatively associated with the means of the progeny of the Marquillo plants studied cytologically. The latter relationship was found to be more marked for Marquis than for Marquillo. No significant association could be demonstrated between either the different cytological aberrations in Minn. No. 2303 or the cytological aberrations and the variability or means of the characters of the progeny. These results with Minn. No. 2303 may be accounted for by assuming that it is essentially a homogeneous population so far as cytological aberrations are concerned. This assumption is not without some foundation as Minn. No. 2303 is not as far removed from an individual plant selection as either Marquillo or Marquis. The results with Marquillo and Marquis are explainable if these two varieties are composed of a heterogeneous population as far as cytological aberrations are concerned. In this case, selection within either Marquillo or Marquis would be expected to produce a strain with a lower percentage of cytological aberrations than the parents.

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CORRELATION STUDIES WITH STRAINS OF FLAX WITH PARTICULAR REFERENCE TO THE QUANTITY AND QUALITY OF THE OIL[1]

I. J. JOHNSON[2]

As new varieties of flax are being developed to meet more specifically the demands of the grower and purchaser of flaxseed, it becomes apparent that more data are needed on the relationship between plant and seed characters and the composition of the seed. In recent years cross breeding has been used as a means of varietal improvement. Since an increase in the percentage and iodine number of the oil is desirable, a careful survey is needed of the existing varieties to find suitable parental material for crossing. The relation of plant and seed characters to the chemical composition of the seed should furnish a valuable criterion to aid in the selection of the better parents and their hybrid progeny. A knowledge of these relationships should facilitate selection of the most desirable progenies in segregating generations.

Relatively little is known regarding the extent of the statistical significance of relationships between plant or seed characters and the composition of flaxseed. The conclusions drawn from the early studies on this problem have been based on observation rather than on statistical methods. As early as 1907, Leather (4)[3] concluded from an analysis of flaxseed secured from several provinces in India that there was no appreciable relation between seed size and oil content. Eyre and Fisher (2) observed that the large-seeded varieties usually have the highest oil content. This observation was later confirmed by Coleman and Fellows (1) who studied the relation between the physical factors influencing the commercial grade of flaxseed and the oil content of the seed. Coleman and Fellows studied the

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[2]Assistant Agronomist. The author wishes to express his appreciation to Prof. A. C. Arny for providing the seed for chemical analysis and the data from the rod row nursery; to Dr. H. K. Hayes, for his suggestions in summarizing and presenting the results of these experiments; and to the Archer-Daniels-Midland Co., Minneapolis, Minn., for the determinations of the percentage of oil and the iodine numbers.

[3]Reference by number is to "Literature Cited," p. 543.

relation of test weight per bushel, moisture percentage, damaged flaxseed, foreign material in flaxseed, color of the seed, and size of seed to the percentage of oil. No relation was observed between oil content and test weight per bushel, color of the seed, or the percentage of damaged kernels. The relation between oil content and the percentage of foreign material in the seed was dependent on the character and quality of the foreign material present. A fairly strong relation was found between the weight per 1,000 seeds and oil content.

MATERIALS AND METHODS

A rather extensive yield trial of 46 varieties and crosses of flax grown in replicated rod-row trials during 1929 and 1930 at University Farm, St. Paul, Minn., gave an opportunity to study varietal differences in percentage and iodine number of the oil and their relation to plant and seed characters. Among the varieties and crosses were included Argentine and domestic types with selections and crosses of each, thus giving a wide range of agronomic characters. The same varieties were included in the test for a 2-year period which made it possible to study inter-annual correlations for the purpose of learning the extent to which the characters were subject to heritable differences.

The characters studied in each of the two years included the percentage of oil, dry weight of 1,000 seeds, date of maturity, and the number of days from full bloom to maturity. In 1930, the iodine number of the oil was also included in the character studied.

During both years the percentage of oil and in 1930 the iodine number were correlated with each of the other characters by means of simple and partial correlations. The interpretation of the significance of the correlation coefficients was made in accordance with the method outlined by Fisher (3), which is of special value in the interpretation of statistical constants derived from relatively small populations. In the above study of the 46 varieties, simple correlation coefficients of approximately .2875, .3384, and .3721 would be required to give odds of 19:1, 49:1, and 99:1, respectively, that such correlations were significant. In the partial correlations where two variables were held constant, correlation coefficients of approximately .3044, .3578, and .3932 would be required to give the above odds.

The standard methods of the Association of Official Agricultural Chemists were used to determine the percentage and iodine number of the oil. The flaxseed was finely ground in a special mill described in detail by Coleman and Fellows (1). Duplicate 4-gram samples

were used in the determination of the oil content and the ether extract dried in a vacuum oven. Duplicate portions of the extracted oil were used for the determination of the iodine number, Wiji's solution being used in all determinations.

EXPERIMENTAL RESULTS

THE SIMPLE CORRELATIONS

A summary of the simple correlations of oil content and iodine number with each of the other variables is given in Table 1. Additional correlations obtained for the purpose of calculating the partial correlations are also presented there.

TABLE 1.—*Interrelationship of characters as shown by simple correlation coefficients.*

Characters correlated	Correlation coefficients	
	1929	1930
Per cent oil and		
Weight of 1,000 seeds	.7159	.7782
Date ripe	.3384	.4855
Number of days from full bloom to maturity	.5993	.6221
Weight of 1,000 seeds and		
Date ripe	.5583	.5293
Number of days from full bloom to maturity	.7908	.6672
Date ripe and		
Number of days from full bloom to maturity	.6721	.6321
Iodine number and		
Per cent oil	-----	—.0565
Weight of 1,000 seeds	——	—.3087
Date ripe	- —	—.1535
Number of days from full bloom to maturity	——	—.0487

The high correlation coefficients of .7159 and .7782 between the percentage of oil and the weight of 1,000 seeds in 1929 and 1930, respectively, indicate a very close positive relationship between these two variables. These results confirm the observation of Eyre and Fisher (2) and Coleman and Fellows (1), but are not in agreement with those of Leather (4). The justification for Leather's conclusion is open to question since the samples used in the study were grown under different climatic conditions and therefore not entirely comparable.

The correlations of .3384 and .4855 between the percentage of oil and date ripe likewise show a fairly strong positive relationship, particularly in 1930. This would suggest that high oil content is favored by delayed maturity. Since some of the late- and early-maturing varieties bloom at very nearly the same date, a correlation

between the number of days from full bloom to maturity and the percentage of oil should show more clearly the relation between the length of the seed-forming period and the oil content. This correlation gave coefficients of .5993 and .6221 which are considerably higher than between date ripe and oil content and therefore indicate that this relationship may be of considerable importance.

The correlations between the iodine number and all characters studied show negative relationships. The highest correlation, —.3087, was between the iodine number and the weight of 1,000 seeds. The odds are somewhat in excess of 19:1 that this relationship is significant. The very low correlations between the iodine number and percentage of oil, date ripe, and the number of days from full bloom to maturity suggest that the iodine number is not conditioned by the same factors that influence oil content in flaxseed. Although the correlations with iodine number are not statistically significant, they are, nevertheless, very important from a breeding standpoint. A high positive correlation between oil content and iodine number would greatly simplify selection for this desired combination. Conversely, a high negative correlation would have made such an objective quite difficult. The lack of a significant correlation between these two variables suggests independent inheritance which should make possible the combination of these desirable characters through crossing.

THE PARTIAL CORRELATIONS

Although the simple correlations are useful in determining the degree of relationship between two variables, it is often desirable to study these relationships by removing the influence of other variables. The partial correlation coefficients were calculated for the percentage of oil and iodine number with each of the other variables held constant. The data are summarized in Table 2.

An analysis of these partial correlations shows that the weight of 1,000 seeds gives the only statistically significant relation to the percentage of oil. These coefficients of .6751 and .7029 in 1929 and 1930, respectively, with date ripe constant ($r_{12.3}$) and .4939 and .6226 with number of days from full bloom to ripe constant ($r_{12.4}$) are only slightly less than found by the simple correlations, and therefore the removal in the partial correlation of the influence of these two variables has not greatly modified the results. This high correlation again emphasizes the importance of seed size as an aid in the selection of hybrids from crosses of large- and small-seeded parents.

The correlations between percentage of oil and date ripe and percentage of oil and number of days from full bloom to ripe, while

significant in simple correlations, are not significant in partial correlation during either of the two years. The reduction in size of these coefficients in partial correlation is readily explained by an exami-

TABLE 2.—*Comparison of simple correlation coefficients and partial correlation coefficients in flaxseed for percentage oil and iodine number with weight of 1,000 seeds, date ripe, and number of days from full bloom to ripe.*

Characters correlated in simple correlations	Correlation coefficient		Partial correlations*	Partial correlation coefficients	
	1929	1930		1929	1930
Percent oil and weight of 1,000 seeds	.7159	.7782	r 12.3	.6751	.7029
			r 12.4	.4939	.6226
Percent oil and date ripe	.3384	.4855	r 13.2	—.1062	.1383
Percent oil and number of days from full bloom to ripe	.5993	.6221	r 14.2	.0777	.2200
Iodine number and percent oil	——	—.0565	r 51.23	——	.2847
			r 51.24	——	.2720
Iodine number and weight of 1,000 seeds	——	—.3087	r 52.13	——	—.4019
			r 52.14	——	—.4480
Iodine number and date ripe	——	—.1535	r 53.12	——	—.0321
Iodine number and number of days from full bloom to ripe	——	—.0487	r 54.12	——	.1663

*1 = percent oil, 2 = weight of 1,000 seeds, 3 = date ripe, 4 = number of days from full bloom to ripe, 5 = iodine number.

nation of the simple correlation coefficient of seed size and date ripe and seed size with number of days from full bloom to ripe (Table 1). The high correlation coefficients of seed size with date ripe, number of days from full bloom to ripe, and oil content have been responsible for the high correlations of oil content with date ripe and number of days from full bloom to ripe. When the influence of seed size was removed in the partial correlations, the true measure of its relation to oil content was secured.

The correlation coefficient between iodine number and oil content was increased from —.0565 in the simple correlation to .2720 in the partial correlation with the influence of seed size and number of days from full bloom to ripe removed, and to .2847 with seed size and date ripe constant. Although the odds are less than 19:1 that these partial correlations are significant, a positive correlation between these two variables is important in flax breeding for a combination of high oil content and high iodine number.

The significant negative partial correlations of —.4480 between the iodine number and seed weight with percentage of oil and length of seed-forming period constant and of —.4019 with the influence of percentage of oil and date ripe removed are somewhat higher than found in the simple correlation between these two variables (Table 2).

The partial correlations between iodine number and date of maturity ($r_{53.12}$) of —.0321 and between iodine number and number of days from full bloom to maturity ($r_{54.12}$) of .1663 are not greatly different than the coefficients secured in the simple correlations. Their lack of relationship to iodine number minimizes their value as a criterion of seed composition

THE MULTIPLE CORRELATIONS

The multiple correlations of the percentage of oil and iodine number with the other variables indicate the extent to which the sum of the variables studied have influenced the composition of the seed. The multiple correlation of the percentage of oil with weight of 1,000 seeds, date ripe, and number of days from full bloom to ripe ($R_{1.234}$) was found to be .7212 in 1929 and .7908 in 1930. These high coefficients indicate that the total effect of these characters determines to a considerable extent the percentage of oil. The relatively low multiple correlation of iodine number with other characters ($R_{5.124}$) of .4510 and ($R_{5.123}$) of .4263 indicates that the greater part of the variables which condition the iodine number of the oil have not been accounted for in this study, and that the iodine number is probably inherited independently of the characters studied.

INTER-ANNUAL CORRELATIONS

Since the same varieties were included in the test for a 2-year period, it was possible to study inter-annual correlations for the purpose of learning the extent to which the characters used were subject to heritable differences. The correlations between 1929 and 1930 were found to be high for each of the four characters studied for the 2-year period. With the percentage of oil the correlation of .8639 between two widely different seasons indicates that this character is quite constant in its expression. The inter-annual correlation of .9502 for the dry weight of 1,000 seeds likewise shows this character to be very highly constant. The correlations of .5088 for date ripe and .6979 for the number of days from full bloom to maturity suggest that these characters are influenced more by environmental differences than the percentage of oil or seed weight. The lower correlation between these two characters may be explained in part by the deficiency of moisture at University Farm in 1930 which resulted in a reduction in range of maturity among the 46 varieties to only 5 days as compared to the varietal range of 14 days in 1929.

SUMMARY AND CONCLUSIONS

To study the percentage and iodine number of the oil and their relation to plant and seed characters, 46 strains of flax were grown in

1929 and 1930 in replicated rod-row plats. The strains used included domestic and foreign types with crosses and selections in each, and gave a wide range in the characters studied. During both years the percentage of oil and in 1930 the iodine number were correlated with each of the other characters studied by means of simple, partial, and multiple correlations.

Significant positive simple correlations were found between the oil content and weight of 1,000 seeds, date ripe, and number of days from full bloom to maturity. Negative simple correlations were secured between iodine number and percentage of oil, weight of 1,000 seeds, date ripe, and number of days from full bloom to maturity. The simple negative correlation between iodine number and weight of 1,000 seeds was statistically significant by Fisher's method of interpretation. Other simple negative correlations with iodine number were not significant.

A further study of these relationships made in partial correlations gave a high positive correlation between the percentage of oil and weight of 1,000 seeds when either date ripe or number of days from full bloom to maturity was held constant.

Partial correlations between the percentage of oil and date ripe and between the percentage of oil and number of days from full bloom to maturity were not significant when seed size was held constant.

A significant partial negative correlation was obtained between iodine number and weight of 1,000 seeds when oil content and either date ripe or number of days from full bloom to maturity was held constant. Other partial correlations with iodine number were not significant

The high multiple correlation between the percentage of oil and the variables studied indicates that the oil content of the seed is dependent to a considerable extent on the same factors that condition seed size, date ripe, and number of days from full bloom to maturity. The low multiple correlation of iodine number with these variables suggests that the iodine number is inherited independently of the plant and seed characters studied.

Inter-annual correlations of oil content, seed weight, date ripe, and number of days from full bloom to maturity indicate that these characters are relatively constant in their inheritance.

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COMPARISON OF CHAMBER AND FIELD GERMINATION TESTS OF SOYBEANS[1]

G. H. CUTLER[2]

There seems to be an opinion current among soybean growers that soybean seed germinates better in the field than the chamber test would seem to warrant. In other words, field germination appears to be higher than the chamber test. This paper will report a series of tests on the germinability of soybean seeds when germinated in the chamber and under field conditions, respectively.

In chamber and soil tests made in the greenhouse with crimson clover, Goss[3] reports an 8% increase in germination in favor of the chamber tests where 164 samples were taken. Whitcomb[4] made comparative tests with five different crop seeds, *viz.*, wheat, oats, flax, corn, and peas, and reports that the chamber tests averaged 16.5% higher than corresponding field tests.

In further tests with wheat, oats, barley, flax, rye, red clover, alfalfa, sweet clover, and corn, Whitcomb[5] reports an average of 24% higher germination in chamber than in field tests.

From these tests Whitcomb draws the conclusion that chamber or laboratory germination tests may be expected to be higher than field tests and lays down the general principle that the difference in favor of chamber tests will vary inversely with the size of the seed. In other words, the differential, if any, in favor of the chamber tests as applied to different crop species increases as the size of the seed decreases.

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Also presented at the annual meeting of the Society held in Chicago, Ill., November 20, 1931. Received for publication December 8, 1931.

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[5]WHITCOMB, W. O. Correlation of laboratory and field germination tests. Proc. 16th Ann. Meet., Assoc. Off. Seed Anal. of Amer., 60–62. 1924.

MATERIALS AND METHODS

The experimental materials from which these data were derived consist of the Manchu and Dunfield varieties. These varieties and their derivatives are probably the ones most commonly grown in Indiana at the present time.

The chamber tests were made in the station germination laboratory directed by the office of the State Chemist, cooperating with the Bureau of Plant Industry. Tests of 100 seeds were made in duplicate at alternating temperatures of 30°C in the daytime and 20°C during the night, over a period of 8 days, in the Minnesota Germinator, according to the usual standard method.

Most of the field data were obtained from rod-row tests made in quadruplicate,[6] consisting of 150 seeds or more of each in rows 30 inches apart. The seeds were planted from 2 to 3 inches deep and spaced about 2 inches apart. The soil was free from weeds and typical of average farm conditions for the soil types represented by the soils and crops farm at Lafayette.

All samples, both for the chamber and the field tests, were taken by one person at random. The seed from which the samples were drawn consisted of the bulk threshed sample which had not been graded or selected. No split, cracked, or black seeds were included. Field counts were made when the plants were from 2 to 8 inches high or from 20 to 30 days after planting. One person made all the counts in the field each season.

EXPERIMENTAL RESULTS

Data are presented in Tables 1 and 2 from a study of tests made with 40 pure line strains of Manchu and a small number of pure line strains of Dunfield during the seasons of 1928, 1929, 1930, and 1931.[7]

TABLE 1.—*Chamber and field germination tests of Manchu soybeans, 1928–31.*

Kind of test	No. of tests	Mean %	S. D.	C. V.
Chamber	320	86.09 ± 0.52	9.8 ± 0.37	11.38 ± 0.43
Field....	480	81.05 ± 0.24	7.9 ± 0.17	9.68 ± 0.21

Difference 5.04 ± 0.57 in favor of the chamber test

The average difference of 5.04 ± 0.57 in favor of the chamber test is statistically significant in the Manchu variety.

[6]Duplicate tests in 1928.

[7]While the tests were made from 1928–31, inclusive, the seed in each case was produced in the preceding season.

TABLE 2.—*Chamber and field germination tests of Dunfield soybeans, 1928–31.*

Kind of test	No. of tests	Average %
Chamber..	9	88.56
Field..	24	83.06

Difference 5.50 in favor of the chamber test

While the number of tests is limited, they cover 4 years and lend support to the results obtained with the Manchu variety.

From these data it seems fair to conclude that from the average results of the 4 years the Manchu and Dunfield varieties of soybeans gave significantly higher germination in the chamber than in the field. These results conform to the general principle laid down by Whitcomb in respect to the relation of size of seed and germination, hence the behavior of soybeans might be expected to be similar to that of corn and peas as reported by him.

While these results seem quite conclusive for the varieties studied, it does not necessarily follow that they will apply to all varieties or strains, for all seasons, or for seed that has been well graded. In fact, exceptions have been found and are here reported under strain and seasonal differences.

STRAIN DIFFERENCES

In the Manchu variety, 3 out of the 40 pure line strains (Table 3) gave a higher percentage germination in the field than in the chamber.

TABLE 3.—*Chamber and field germination tests of three Manchu pure line strains, 1928–31.*

Strains No.	Chamber germination* %	Field germination* %	Difference in favor of	
			Chamber %	Field %
29	72.25	79.05	—	3.80
32.	76.00	81.45	—	5.45
40	77.25	83.82	—	6.57
Average	—	—	—	5.24%

*Average of 4 years.

Though the number of tests is small, these strains of Manchu consistently gave a higher germination in favor of the field tests.

SEASONAL DIFFERENCES

In 1929 and 1931, the 40 strains of Manchu did not reveal a significant difference in favor of either the chamber or field tests. This is well illustrated in Fig. 1.

It will be seen that in 1929 the difference was in favor of the chamber test by only 1.84% germination, while in 1931 the difference of 1.35% was in favor of the field test.

DISCUSSION

In attempting to analyze the results obtained some of the factors that appear to have been influential in the tests were examined.

SEED CONDITION

Table 4 reveals data relative to the germinability of the seed of the Manchu variety for each of the 4 years under test.

It is at once apparent that the germinability of the Manchu seed varied considerably from season to season. Three factors seem to stand out rather prominently in Table 4, *viz.*, (1) the differential in favor of either chamber or field varied from season to season and did not bear a constant relation to the 8-day chamber tests; (2) the percentage of hard seeds and non-germinable seeds varied from season to season; and (3) the differential between chamber and field tests was in favor, though not significantly so, of the field test (1931) when the percentages of hard seeds and non-germinable seeds, respectively, were highest. In 1929 the difference was in favor, though not significantly so, of the chamber tests. Here the percentage of non-germinable seeds was relatively high.

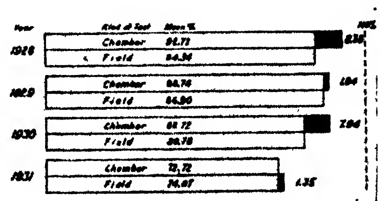

FIG. 1.—Chamber and field germination tests of Manchu soybeans.

TABLE 4.—*Chamber and field germination and seed condition in Manchu soybeans, 1928–31.*

Year	8-day chamber test %	Field test %	Hard seeds %	Non-germinable seeds %	Difference in favor of	
					Chamber %	Field %
1928	92.72	84.34	1.74*	5.54	8.38	—
1929	88.74	86.90	0.38	10.87	1.84	—
1930	88.72	80.78	0.84	10.44	7.94	—
1931	72.72	74.07	2.56	24.72	—	1.35

*The counts on field germination were made 15 days after planting, probably before the hard seeds had time to germinate, hence they did not help the field germination.

In this connection it is of interest to note that among the three strains of Manchu referred to in Table 3, No. 32 and No. 40 gave a significantly higher percentage germination in the field than in the

chamber test. The percentages of hard seeds in these two strains were high, 13.5 and 8.0%, respectively, while strain No. 29 had no hard seeds but rather a consistently high percentage of non-germinable seeds.

These facts seem to indicate that with the Manchu variety the difference, if any, between chamber and field germination will depend, to some extent at least, upon the seed condition of the sample used.

It is well known that hard seededness exists in soybeans and that seeds with hard seed coats are potentially germinable when placed in the soil. The non-germinable beans, on the other hand, are presumably not capable of germinating in the field. How many of these actually germinate has not yet been ascertained.

SEASONAL CONDITIONS

Another factor which seems to have a bearing upon the results is that of seasonal conditions following planting. Temperature and rainfall records for the interval of 30 days following planting are shown in Table 5 for the seasons of 1928–31.

TABLE 5.—*Temperature and rainfall records during the 30-day interval following planting, 1928–31, Lafayette, Indiana.**

Year	Interval of time	Mean daily temperature, °F.	Total rainfall, in.	Germination in		Difference in favor of	
				Chamber %	Field %	Chamber %	Field %
1928	May 14–June 18	62.72°	5.8	92.72	84.34	8.38	—
1929	May 24–June 25	68.92°	6.5	88.74	86.90	1.84	—
1930	May 13–June 15	62.24°	2.5	88.72	80.78	7.94	—
1931	May 24–June 23	71.18°	3.4	72.72	74.07	—	1.35

*Temperature and rainfall records from the State Chemist's office. Beans planted May 14, 1928; May 24, 1929; May 13, 1930; and May 24, 1931.

From Table 5 it will be seen that the mean daily temperatures in 1928 and 1930 were very similar, though they were lower by 6° and 8°, respectively, than in 1929 and 1931. It seems probable that with the possible exception of 1930 the rainfall was satisfactory for germination.

It is of interest to note that the more favorable mean daily temperatures of 1929 and 1931 were associated with sufficiently relatively better field germination to make the chamber and field germination substantially equal. On the other hand, with lower mean daily temperatures for the 30 days following planting in both 1928 and 1930, the difference in germination was significantly in favor of the chamber tests, and this despite the fact that the germinability of the seed in the chamber was as good or better than that in 1929 and 1931.

SOIL CONDITIONS

In 1930 and 1931 check plats of Manchu No. 35 were grown at regular intervals throughout the testing grounds. Coefficients of variability in germination were determined on the 40 strains as well as the checks (Table 6).

It will be seen from these data that the variability of the check (Manchu No. 35) in 1930 was nearly as great as in the 40 strains. Furthermore, the variability of the check was much greater in 1930 than in 1931. In 1931, on the other hand, the variability of the check was very much less than that of the 40 strains grown under similar conditions. The influence of soil conditions on field germination in soybeans is further illustrated in Fig. 2.

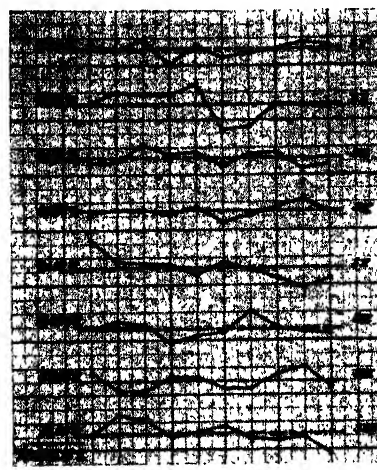

FIG. 2.—Field germination of Manchu strain No. 35, 1930. C. V. = 5.29 ±0.28.

SUMMARY

In a 4-year test ungraded seed of the Manchu variety of soybeans gave 5.04 ± 0.57% better germination in the chamber than in the field, with 320 chamber tests and 480 field tests. During the same years ungraded seed of the Dunfield variety gave similar results on a limited number of tests.

TABLE 6.—*Field germination tests of Manchu soybeans, 1930 and 1931.*

Year	Kind	No of tests	Mean	S.D.	C.V.
1930	40 strains	160	80.78±0.32	5.24±0.23	6.49±0.28
1930	Manchu No. 35	80	85.09±0.34	4.50±0.23	5.29±0.28
1931	40 strains	160	74.07±0.31	5.78±0.22	7.81±0.30
1931	Manchu No. 35	80	82.94±0.23	3.09±0.16	3.75±0.20

Three strains of the Manchu variety, *viz.*, Nos. 29, 32, and 40, in a 4-year test, gave a significantly better germination (5.24%) in the field than in the chamber.

Seed condition, seasonal conditions immediately following planting, and soil have an important bearing on the results obtained.

Hard-seededness in a sample is a contributing cause in equalizing chamber and field germination. Non-germinable seeds, as revealed

by the 8-day chamber test, may also have an effect similar to that of hard-seededness.

Favorable temperature and moisture conditions following planting have a profound effect upon field germination and may be instrumental in causing the field germination to be as high or higher than the chamber germination.

An analysis of these data helps to explain the rather current opinion prevailing among soybean growers that field germination in soybeans is often better than the chamber test would seem to warrant.

INHERITANCE OF LINT COLORS IN UPLAND COTTON[1]

J. O. WARE[2]

In a former paper, the writer (14)[3] reported some preliminary inheritance studies with two shades of lint color in Upland (*Gossypium hirsutum*) cotton. In the present report additional work with these two shades of lint color and also results obtained from a study of two other shades of lint color in Upland cotton are given.

The four shades of lint color are dingy brown, borne by the Algerian Brown Lint variety; bright green, borne by the Argentine Green Lint variety; yellowish brown, borne by the Nankeen variety; and rust-colored brown, borne by the Texas Rust variety. Each of these four varieties resemble the other varieties of Upland cotton with the exception of the lint color.

All commercial varieties of the Upland species produce pure white lint. However, sporadic plants, bearing some shade of lint color, do occur in rare instances among the varieties of this species. The varieties characterized by a particular lint color have developed, no doubt, from such plants bearing the given shade of color.

Mell (9), Evans (3), Tyler (13), Balls (1), Watt (15), Brown (2), and Thadani (11, 12) have noted the existence of colored lint kinds of cotton in the Upland species.

REVIEW OF OTHER WORK

In addition to the writer's (14) previous work, Brown (2) has given results of his studies with Nankeen lint. These two reports embrace

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Research Paper No. 285, Journal Series, University of Arkansas. Received for publication December 8, 1931.

[2]Agronomist.

[3]Reference by number is to "Literature Cited," p. 561.

all the inheritance work with lint color among varieties of the Upland species of cotton that has come to the attention of the writer. Three workers have given results of lint color inheritance among other species of cotton or between Upland and other species.

The writer's (14) previous work included two crosses. In the first cross Algerian Brown Lint, having lint of a dingy brown color, was crossed with a normal white-linted variety. In this cross, the F_1 plants uniformly produced lint of a brown-tinged color and the F_2 plants, 802 in number, broke up into a ratio of 1.03 dingy brown: 1.91 brown tinged: 1.06 white. In the second cross, Argentine Green Lint, having lint of a bright green color, was crossed with a normal white-linted variety. In this second cross the F_1 plants uniformly bore lint of a lighter shade of green and the F_2 plants, 170 in number, segregated into a ratio of 0.99 full green: 1.60 lighter green: 1.41 white. This ratio did not approximate the 1:2:1 type very closely, however, the lighter green color of the intermediate plants fading out upon long weather exposure. The classification was made late in the season and, no doubt, some of the faded out light green plants were classified as white. On the other hand, the apparent confusion in classification did not obscure the appearance of the 3:1 ratio. The number of full green plants was an almost exact fourth of the total.

Brown (2) in crossing two upland varieties, Cleveland with white lint and Nankeen with yellowish brown lint, obtained in the F_1 generation "uniform brownish cream-colored lint, intermediate between the two parents in color" and the F_2 "almost an exact 1:2:1 ratio" for lint color.

Kottur (8) made a cross between Dharwar No. 1 (*G. herbaceum*) and Rosea (*G. neglectum*). The lint of the former variety was dull white tinged with red and the lint of the latter was pure white. This investigator in referring to the lint color says, "***this is continued in the F_1 generation. But in the F_2 generation the color segregates, and plants appear which give pure white cotton, and others which give lint with a deep brown tint." He then gives the segregated ratio of 500 F_2 plants as follows: 1.00 brown lint: 1.60 dull white lint: 1.50 pure white lint.

According to Kearney (7), Balls crossed a brown-linted and a white-linted cotton and reported "a distribution in the F_2 of 30 brown, 66 cream, and 32 white" linted plants. Kearney (7) did not state whether both of the parents of Balls' cross were of the Egyptian type or whether one parent was of another species. Since a close 1:2:1 ratio was obtained the parents probably were Egyptian varieties.

In another cross of an Egyptian variety having brown lint and an Upland variety having white lint, Balls (1) obtained in the F_1 generation lint intermediate between that of the two parents or creamy in color. The F_2 generation of this cross segregated giving 12 plants with brown lint, 21 plants with creamy lint, and 11 plants with white lint. The plants with brown lint and with white lint bred true up to the fifth generation, while the creamy-colored types continued to break up as in the F_2 generation. However, Balls stated that while the extracted brown-linted plants never transgressed the limits of "brownness" they were by no means uniform. Some individuals were much darker in color than that of the Egyptian plants, while other individuals were lighter in color than the brown parent.

In a Charara X King cross where the parents were very light brown Egyptian and white Upland, Balls (1) secured an intermediate F_1 as in his previous crosses, "but the F_2 consisted of 9 brownish, 60 creamy, and 109 white" plants.

In Kearney's (7) Holdon X Pima cross the Holdon (Upland) had white lint and the Pima (Egyptian) had pale buff lint. The F_1 generation produced lint "approximately intermediate in color" between that of the two parents, and the F_2 generation, after the plants had been graded according to a color scale, showed a unimodal frequency curve.

In a study of the genetical characters of cotton the results obtained often depend upon whether the parental sources are within a species or are combined from different species.

Harland (5) studied three characters, *viz.*, petal spot, flower color, and pollen color, in both interspecific and intraspecific crosses, and found that the inheritance of the varietal crosses was simple, clear-cut, monohybrid segregation, while that of the species hybrid was quantitative or blended. In summing up these results Harland says, "Pollen color, spot, and corolla color are determined by a single factor pair in both varietal and interspecific crosses. In varietal crosses there is segregation of the main gene alone, whereas in the interspecific cross there is segregation of modifiers which may partially or in some cases, entirely, obscure the distinction between dominant and recessive. There is thus no real difference in the mechanism of inheritance in interspecific from that which exists in varietal crosses."

In the fiber color studies of other investigators to which the writer has heretofore referred, there has been some lack of agreement in results. In Brown's work and in the writer's previous work with varieties of Upland cotton, clear-cut monohybrid ratios were shown. Also, in one of Balls' crosses, which was apparently between two

Egyptian varieties, there was a decided monohybrid inheritance shown. On the other hand, Balls' work and Kearney's work with interspecific crosses did not always show clear-cut segregation for lint color in the F_2 generation. In one of Balls' interspecific crosses he found considerable variation within his color segregates and in his other interspecific cross there seemed to be no agreement whatever between his numbers and a simple Mendelian ratio. In Kearney's interspecific cross, as heretofore stated, he obtained a unimodal distribution in his F_2 generation. Kottur in his interspecific cross did not get very good agreement to a 1:2:1 ratio. However, the *G. herbaceum* and *G. neglectum* cross possibly should not be classed as an interspecific hybrid in the same way as is Upland and Egyptian or as is Upland and Sea Island. Asiatic cottons are much more nearly related to one another than the species of the American group and the former group, no doubt, differ less among themselves in their complements of modifying factors than do the members of the latter group. Harland (4) states that "there is only one species of cultivated Asiatic cotton."

Since the greater part of the inheritance work with lint color has been done by means of crossing species rather than varieties within a species and since there are several shades of lint color in Upland cotton not completely worked out genetically, the writer directed his work to four shades of color found in the Upland cotton.

EXPERIMENTAL MATERIAL AND METHODS

Plants from Upland varieties representing the four shades of color were crossed respectively with plants of Upland varieties bearing white lint. The list of the crosses are given below, however, the order is not the same as given in the writer's preliminary work or in the introduction of this paper. As heretofore cited, the writer's previous work included some study of Algerian Brown Lint and Argentine Green Lint crossed respectively with white-linted Upland varieties. The crosses were as follows:

Cross I, Texas Rust (rust-colored lint) X Hite (white lint)

Cross II, Algerian Brown (dingy brown-colored lint) X Sproull (white lint)

Cross III, Nankeen (yellowish brown-colored lint) X Rowden (white lint)

Cross IV, Argentine Green (green-colored lint) X Trice (white lint)

DESCRIPTION OF COLORS

The descriptions of the four fiber colors used in the crosses are as follows: The three brown shades vary from a pale brown or a rust color to a deep brownish yellow. Texas Rust, as the name implies, is the pale brown or rust-colored shade. The Algerian Brown has more color than the Texas Rust and is called a dingy brown. The Nankeen is more intense in color than the Algerian Brown. The Nankeen is the deep yellowish brown color. The intensity of the brown colors increases with the types in the order named. Where the brown colors have been crossed with white lint, the respective shades of the F_1 generation, though considerably diluted, increase or decrease in the same order as the brown parents. The F_1 lint from the Nankeen-normal cross possesses much more color than the F_1 lint from the Algerian-normal or the Texas Rust-normal hybrids. The color of the first generation lint from the Nankeen-normal hybrid is almost the same in intensity as that of the pure Algerian Brown, but it is of a more yellowish cast. The F_1 lint from the other two hybrids is almost white in color, and it requires close observation to distinguish between these hybrids and the pure white lint. However, the material can be accurately classified, if the work is done before the types become too much weathered. The pure Nankeen, the pure white, and the F_1 generation from these types are very easily graded and make satisfactory material for such classification. Upon exposure to the sun's rays or to the weather elements, the Nankeen or its hybrid with white lint does not fade materially. Rather the sunshine tends to intensify further the pure Nankeen lint.

The Argentine Green Lint is an intense green, but after a period of weather exposure outer portions of the locks fade somewhat and develop tawny spots (2). These brownish yellow spots penetrate the seed cotton to some extent, but the intense green color remains unchanged for some time in the portions of the bolls adjacent to the base of the bur. A dirty, oily, brownish color sometimes occurs in the more exposed portions of the cotton. The lint of the F_1 generation, resulting from the crossing of the green lint variety with any normal lint variety, assumes an intergrade color between the pure green and the pure white. This grade of cotton, however, is not intermediate between the two parents, but tends to be nearer that of the green parent. The F_1 lint has a greater tendency to fade or bleach out and does not develop to as great an extent the tawny or oily appearance. Upon several week's exposure to the sun's rays and to extensive rains and dews over a period of time, the first generation lint may lose all of its green coloring. When the bolls first open, the full green

lint and the intermediate lint are not easily differentiated in every instance. In the F_2 generation, when the two parental types and the intermediate recur, grading is not always easily accomplished, if the classification is undertaken at an improper time. Too early in the season the pure green and the intermediate green types may be confused, and too late in the season, the filtered out green of the intermediate and the mildewed white may be difficult to separate. The better time to classify this material is 1 or 2 weeks after the bolls open. If the plants are large and have many bolls which open at consecutive periods, the grading is rendered much more easy. However, to get large numbers of individuals, the tendency is to leave the plants so close in the row that only a few bolls mature to the plant. The green lint is associated with green seed, the green seed color being due to green fuzz. The color of the lint or the floss probably could be considered as a result of an extension factor which diffuses the green color from the fuzz into the floss. This theory might also be applied to the origin of the brown colors as brown fuzz is associated with brown lint.

THE TEXTURE OF THE LINT

The texture of the three kinds of brown lint is coarse and short, while the texture of the green lint is soft and silky and not short in length. The fine and soft texture of the lint found in the Argentine Green Lint parents continues to be associated with the full green in the F_2 and subsequent generations. The lint of the Argentine Green Lint variety was much finer and more silky in texture than that of the Trice variety. The lint of the white-linted plants in the F_2 and subsequent generations was similar in texture to that of the Trice parents. Also, the lint of the F_1 plants and the intermediate plants of the following generations was similar to the Trice lint in texture. The coarse texture of the lint is dominant and the fine texture seems to be completely linked with the green color, that is, this condition appears to be the case in the Argentine Green Lint X Trice cross. No heritable tendencies in the texture of the brown lint types could be ascertained.

RESULTS

CROSS I. RUST-COLORED LINT X WHITE

The F_1 plants from the Texas Rust X Hite cross uniformly bore a very pale, rust-colored lint nearly white but were easily distinguished from that of the pure white Hite parent. The lint color of the F_1 plants and of the heterozygous plants in the F_2 generation was more

nearly the color of that of the white parent than of the rust-colored parent, but for convenience the intergrade color is designated as intermediate. A total of 897 F_2 plants were grown and the results of their segregation are given in Table 1.

TABLE 1.—*F_2 segregation from the rust-colored X white lint cross.*

Segregated types	Observed number (O)	Calculated number (C)	$\frac{(O-C)^2}{C}$
Rust-colored lint	246	224.25	2.175
Intermediate color	436	448.50	0.348
White lint	215	224.25	0.382
Total	897	897.00	2.905
		$\chi^2 = 2.91$	P = 0.246

Where three classes of plants appeared in the segregation, the χ^2 method described by Hayes and Garber (6) and by Pearson (10) for testing the goodness of fit between observed and theoretical or calculated numbers was used. The value for P (Pearson's tables) of 0.05 or greater was interpreted as being statistically significant. The value of 0.05 indicates that a worse fit may be expected only once in 19 trials on the basis of random sampling. In cross I, the P value of 0.246 shows a good fit to the 1:2:1 ratio, which indicates that rust-colored lint is a monohybrid character and inherited according to a modified 3:1 Mendelian fashion.

A few F_3 plants were grown. Those bearing rust-colored or white lint in the second generation bred true in the third for the respective character. The F_2 plants with pale rust-colored or intermediate lint split for lint color in the third generation. No back crossing was done in the Texas Rust X Hite cross.

CROSS II. DINGY BROWN-COLORED LINT X WHITE

The F_1 plants from the Algerian Brown X Sproull cross uniformly produced lint of a very light brown or dingy white color. The F_1 generation lint color approached more nearly the white parental type than that of the dingy brown, however, the difference is observable before unfavorable weather conditions alter the appearances of the lint. The light brown or dingy white type is called intermediate for convenience. Table 2 presents the results of the Algerian Brown X Sproull cross. No back crossing in connection with this cross was carried out, but, in addition to the F_2 generation, third and fourth generation plants were obtained and the data tabulated.

TABLE 2.—F_2, F_3, and F_4 *segregations from the dingy brown-colored X white lint cross.**

Segregated types	Observed number (O)	Calculated number (C)	$\frac{(O-C)^2}{C}$
F_2 Generation			
Dingy brown-colored lint	89	77.25	1.787
Intermediate color	147	154.50	0.364
White lint	73	77.25	0.234
Total	309	309.00	2.385
	——	$\chi^2=2.39$	P. =0.310
F_3 Generation			
Dingy brown-colored lint	146	142.75	0.074
Intermediate color	285	285.50	0.000
White lint	140	142.75	0.053
Total	571	571.00	0.127
		$\chi^2=0.13$	P = >0.606
F_4 Generation			
Dingy brown-colored lint	196	172.25	3.275
Intermediate color	321	344.50	1.603
White lint	172	172.25	0.000
Total	689	689.00	4.878
		$\chi^2=4.88$	P =0.088
F_2, F_3, and F_4 Generations combined (total F_2 equivalent data)			
Dingy brown-colored lint	431	392.25	3.828
Intermediate color	753	784.50	1.264
White lint	385	392.25	0.134
Total	1,569	1,569.00	5.226
		$\chi^2=5.23$	P =0.075

*Progeny from the F_1 and intermediate plants of F_2 and F_3 generations.

According to the χ^2 method for the goodness of fit, the ratios in the F_2, the F_3, and the F_4 generations each approximated the theoretical 1:2:1 ratio in a significant manner. However, the observed number of plants approached the expected number more closely in the second and third generations than in the fourth generation. The observed ratio in the F_3 generation was almost identical in agreement with the theoretical ratio. The combination of all offspring that segregated from intermediate plants also showed a significant fitting to the 1:2:1 ratio, although the value of P for the total segregation indicated a slightly poorer fit than did any of the separate generations.

A poorer fit, as tested by the χ^2 method, is to be expected when

different populations all having deviations in the same direction are combined. This is due to the construction of the formula $\frac{(O - C)^2}{C}$ in which the squaring of the combined (O – C) values for each class increases more rapidly than does the combined C values. It is shown in Table 2 that there is a slight excess of dingy brown-colored segregates.

Several of the plants with dingy brown lint and several of the plants with white lint of both the second and the third generations were propagated as a test of type purity. Forty-four F_2 generation and 33 F_3 generation plants having dingy brown lint bred true for purity of color. Thirty-one F_2 generation and 18 F_3 generation plants with white lint bred true for white lint. Each individual plant passed through the process of hybridization without any shading or blending influence upon color. Both the dingy brown and white progenies were as clear cut and as distinct as the parental types before entering the cross. Each plant in the purity test averaged about 20 offspring.

The lint of the F_1 plants and of the intermediate plants existing in the second and third generations is identical in color. The light brown or dingy white color is unstable and cannot be fixed. It always breaks up into an approximate 1:2:1 ratio.

CROSS III. YELLOWISH BROWN-COLORED LINT X WHITE

The F_1 plants from the Nankeen X Rowden cross uniformly possessed a light shade of yellowish brown color. This color cast, based upon observation, appeared to be practically intermediate between the pure color of Nankeen and that of the white parental strain. The designation of the first generation lint color of this cross as "intermediate" seems to be approximately correct. The Nankeen X Rowden cross was carried through the F_2 generation in detail and back crosses were made on both parental strains. The F_2 generation data appears in Table 3, the F_1 X Nankeen back cross data in Table 4, and the F_1 X Rowden back cross data in Table 5.

TABLE 3.—*F_2 segregation from the yellowish brown colored X white lint cross.*

Segregated types	Observed number (O)	Calculated number (C)	$\frac{(O-C)^2}{C}$
Yellowish brown lint color	583	567.5	0.423
Intermediate color	1,143	1,135.0	0.056
White lint	544	567.5	0.973
Total	2,270	2,270.0	1.452
		$\chi^2 = 1.45$	$P = 0.499$

The value of P for the segregation of the F_2 plants in the Nankeen X Rowden cross shows a very close fit to the 1:2:1 ratio.

The F_2 plants with yellowish brown lint and with white lint each bred true for the parental type of lint color in the third generation. F_2 plants with intermediate lint color when propagated again segregated in the third generation.

TABLE 4.—*Segregation of the F_1 X Nankeen back cross.*

Segregated types	Observed number (O)	Calculated number (C)	(O–C)
Yellowish brown lint color	155	163	8
Intermediate color	171	163	8
Total	326	—	--
Deviation ÷ probable error = 1.32		Odds	1.68:1

TABLE 5. *Segregation of the F_1 X Rowden back cross.*

Segregated types	Observed number (O)	Calculated number (C)	(O–C)
Intermediate color	180	171	9
White lint	162	171	9
Total	342	—	–
Deviation ÷ probable error = 1.45		Odds	2.05:1

Where two classes of plants only were involved, as with the back crosses, the general formula, P. E. $= 0.6745 \sqrt{p\ q\ n}$, for obtaining the probable error of Mendelian ratios was used. In the formula, p and q represent the elements of the ratio in terms of percentage expressed as a decimal fraction, and n is the total number of individuals. Odds of 19:1 or less are considered significant and the conclusion is drawn that the observed numbers fit the ratio.

The backcrosses of the F_1 on both the Nankeen parent and the Rowden parent showed very good fits to the 1:1 ratio, the odds of the former being 1.68:1 and of the latter 2.05:1.

CROSS IV. GREEN-COLORED LINT X WHITE

The F_1 plants from the Argentine Green Lint X Trice cross uniformly produced, as heretofore described, a somewhat lighter shade of green than that of the pure green parent. The F_1 color is nearer to that of the green parental strain than to that of the white lint, but for convenience is called intermediate in color. From the Argentine

Green Lint X Trice cross the F_2 data are reported in Table 6, the F_1 X Argentine Green Lint back cross data in Table 7, and the F_1 X Trice back cross data in Table 8.

TABLE 6.—*F_2 segregation from the green-colored lint X white lint cross.*

Segregated types	Observed number (O)	Calculated number (C)	$\frac{(O-C)^2}{C}$
Green lint	1,068	1,059	0.076
Intermediate color	2,105	2,118	0.079
White lint	1,063	1,059	0.015
Total	4,236	4,236	0.170
		$\chi^2=0.17$	P = >0.606

The very low value of χ^2 and consequently the very high value of P shows an extremely close fit of the segregated types in the F_2 generation of the green lint X white lint cross to the 1:2:1 ratio.

TABLE 7.—*Segregation of the F_1 X Argentine Green Lint back cross.*

Segregated types	Observed number (O)	Calculated number (C)	(O–C)
Green lint	992	972.5	19.5
Intermediate color	953	972.5	19.5
Total	1,945	——	——

Deviation ÷ probable error = 1.31 Odds 1.66:1

Seeds from plants with green lint, from plants with a lighter shade of green lint, and from plants with white lint of the F_2 generation were planted and the third generation grown. The green- and white-linted plants bred true, respectively, for pure green lint and pure white lint. The plants with the lighter shade of green lint segregated as did the progeny of the first generation.

The back crosses of the F_1 on both the Argentine Green Lint parent and the Rowden parent exhibited excellent fits to the 1:1 ratio. The odds of the former were 1.66:1 and of the latter 1.82:1.

TABLE 8.—*Segregation of the F_1 X Trice back cross.*

Segregated types	Observed number (O)	Calculated number (C)	(O–C)
Intermediate color	659	676	17
White lint	693	676	17
Total	1,352	——	——
	Deviation ÷ probable error = 1.37		Odds 1.82:1

SUMMARY

Four sets of crosses, *viz.*, rust-colored lint X white, dingy brown-colored lint X white, yellowish brown-colored lint X white, and green-colored lint X white, were made and the progenies studied. The lint color of the F_1 generation of each cross was an intergrade between that of the respective colored parent and the white parent. Thus, each of the four shades of lint color are incompletely dominant over white lint. The respective crosses when grown in the F_2 segregated into three classes as follows: The colored parental type, an intergrade colored type identical with the F_1 generation, and the white parental type. The colored and white parental types continued to breed true in the following generations, while the intergrade type split up into the three classes as did the progeny of the first generation. In cross II, where the progeny was carried through the F_4 generation, the dingy brown plants and the white plants reproduced themselves and the brown-tinged plants segregated.

In the work reported here, the statistical calculations in most cases indicate close fits of the observed numbers to the calculated numbers in both the 1:2:1 and 1:1 ratios; and in no cases were the goodness of fit tests beyond the limits of what is commonly accepted as significant.

In Upland cotton, each of the four lint colors rust, dingy brown, yellowish brown, and green is a clear-cut monohybrid character and when crossed with its white allelomorph produces an intergrade lint color type in the F_1 generation and in the heterozygous groups of all subsequent generations.

As found in cross IV, fine silky texture of lint seems to be completely linked with full green lint color and coarse lint appears to be dominant over fine lint.

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THE IRON, MANGANESE, COPPER, ZINC, AND IODINE CONTENT OF SOME IMPORTANT FORAGE CROPS[1]

J. S. MCHARGUE, W. R. ROY, AND J. G. PELPHREY[2]

The authors have been interested for some time in the occurrence, distribution, and probable function of some of the less common elements in nature. It has been shown in previous reports[3] that the elements manganese, copper, zinc, and boron have important functions in the growth and metabolism of yeast, molds, plants containing chlorophyll, and animals. It is the purpose of this paper to present data concerning the iron, manganese, copper, zinc, and iodine content of some important forage crops which were grown on the principal geological areas in Kentucky.

During the past 3 years the Departments of Chemistry and Agron-

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omy of the Kentucky Agricultural Experiment Station have been carrying on a cooperative investigation to ascertain if any appreciable differences occur in the mineral content of forage crops grown on the different soil experiment fields maintained in the state. The forage crops were grown on plats of soil which received the following treatments: Check (control), manure, limestone, rock phosphate, superphosphate, and combinations of two or more of these fertilizer materials.

Samples of the forage crops were collected at the proper stage of maturity, air-dried, finely ground, and analyzed for iron, manganese, copper, zinc, and iodine. The average results are given in Table 1.

TABLE 1.—*Iron, copper, manganese, zinc, and iodine content in percentage of moisture-free material of some forage crops grown in Kentucky.*

Crop	Number of samples analyzed	Fe	Cu	Mn	Zn	P.P.B. I
Red clover	22	0.017	0.0017	0.0100	0.0042	116.2
Soybean hay	16	0.025	0.0008	0.0122	0.0051	—
Alsike clover hay	2	0.045	0.0006	0.0090	0.0060	—
Sweet clover hay	1	0.013	0.0009	0.0050	0.0050	—
Alfalfa hay	2	0.015	0.0010	0.0080	0.0050	—
Redtop hay	14	0.014	0.0004	0.0276	0.0023	89.1
Orchard grass hay	9	0.015	0.0005	0.0269	0.0025	117.3
Timothy hay	13	0.013	0.0005	0.0078	0.0042	70.9
Bluegrass hay	1	0.032	0.0014	0.0080	0.0017	—
Corn stover	5	0.020	0.0007	0.0160	0.0058	—
Wheat straw	20	0.011	0.0003	0.0069	0.0017	66.9
Wheat grain	20	0.008	0.0006	0.0060	0.0065	—

The number of analyses of independent samples averaged is stated in the second column of the table. The number of ounces of each element in a ton (2,000 pounds) of moisture-free material, computed from these figures, is stated in Table 2.

TABLE 2.—*Ounces of element per 2,000 pounds of moisture-free forage crop.*

Crop	Number of samples analyzed	Fe	Cu	Mn	Zn	I
Red clover hay	22	5.44	0.54	3.2	1.34	0.0037
Soybean hay	16	8.00	0.26	3.9	1.63	—
Alsike clover hay	2	14.40	0.19	2.88	1.92	—
Sweet clover hay	1	4.16	0.29	1.60	1.60	—
Alfalfa hay	2	4.80	0.32	2.56	1.60	—
Redtop hay	14	4.48	0.13	8.83	0.74	0.0029
Orchard grass hay	9	4.80	0.16	8.61	0.80	0.0037
Timothy hay	13	4.16	0.16	2.50	1.34	0.0023
Bluegrass hay	1	10.24	0.45	2.56	0.54	—
Corn stover	5	6.40	0.22	5.12	1.86	—
Wheat straw	20	3.52	0.10	2.21	0.54	0.0022
Wheat grain	20	2.56	0.19	1.92	2.08	—

DISCUSSION OF RESULTS

These different forage crops show considerable differences in the amounts of the various metals they contain. Most of the forage crops contain a larger amount of iron than of copper, manganese, or zinc; however, redtop and orchard grass contain nearly twice as much manganese as iron. These two grasses are comparatively low in copper and zinc. The maximum iron content occurs in alsike clover and the minimum in wheat grain. The maximum copper content was found in red clover. Kentucky bluegrass contained nearly as much and alfalfa a little less copper than bluegrass. Wheat straw contained the least copper of any of the crops analyzed. The leguminous crops averaged appreciably more copper than the grasses. The largest quantities of manganese were found in redtop, orchard grass, corn stover, soybeans, and red clover, in diminishing order. Zinc occurred in the largest amounts in wheat grains, alsike clover, and corn stover. As a rule, more zinc was found in the leguminous crops than in the grasses. Red clover and orchard grass contained the largest amounts of iodine. The results for iodine are only approximate because no satisfactory method for the determination of iodine in forage crops was available.

EFFECT OF ADDITION OF LIMESTONE ON MANGANESE CONTENT OF CROPS

In a good many cases where limestone was added in the fertilizer treatments of a plat there was often a marked diminution in the manganese content of the crop as compared with the manganese content of the same crop grown on an adjacent plat to which no limestone was added. This is shown in Table 3.

TABLE 3.—*Percentage of manganese in moisture-free crops from fertilized plats.*

Crop	No fertilizer	Manure and limestone	Manure and superphosphate	Manure, limestone, and superphosphate
Soybeans	0.020	0.006	0.028	0.006
Redtop	0.033	0.011	0.031	0.012
Red clover	0.010	0.006	0.010	0.009
Timothy	0.011	0.007	——	0.006

The most probable explanation of this observation is that the limestone added has diminished the acidity of the soil. The addition of too much limestone may change soluble manganese into the insoluble condition and thereby produce chlorosis in some plants and result in diminished yields. However, moderate applications of limestone may

increase the yield of the crop and also diminish the manganese content of the crop.

SUMMARY

Important forage crops assimilate varying amounts of iron, manganese, copper, zinc, and iodine from the soil. Those crops that contain the largest amount of any one of these elements usually contain considerably less of the other elements considered. Therefore, a mixture of forage crops will afford a better balanced ration in regard to iron, manganese, copper, zinc, and iodine for livestock than will any single species. It is the opinion of the authors that the forage crops produced on Kentucky soils contain adequate amounts of the less common elements, such as iron, copper, manganese, zinc, and iodine, to meet the normal requirements of livestock if a mixture of the legumes and grasses is fed.

ORGANIC MATTER AS A FACTOR IN CLASSIFICATION OF THE SOILS OF DRY REGIONS[1]

CHAS. F. SHAW[2]

In the regions of arid and semi-arid climates and in those regions of sub-humid climate where the precipitation is periodic with wet winters and dry summers, organic matter plays a relatively minor part in determining the characteristics of soil profiles. During the dry season when temperatures are high any accumulation of organic debris upon the surface becomes thoroughly dessicated. The components, whether pine needles, leaves of deciduous trees, herbaceous remains, or grasses, become tinder-dry and brittle, breaking readily when trodden upon or handled. By mid-summer the surface soils are thoroughly dried out and by early autumn the soil profile becomes dry to depths of 2 to 6 or more feet, depending on the depth and density of root population.

During this dry season the temperatures of both the air and soil are high. Weather records show the mean monthly temperature at Imperial to be above 70°F from April to October, inclusive, and above 90°F during July and August; at Davis in the Sacramento Valley, to be between 60° and 75°F from May to October, inclusive; at Emigrant Gap in the Sierras at an elevation of 5,230 feet, to be

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between 60° and 70°F during June to September, inclusive; while at Eureka on the northwest coast in the belt of summer fogs, the mean monthly temperatures are reported as between 46° and 56°F throughout the entire year.

Smith (5)[3] found the mean monthly temperatures in the upper 2 feet of a plat of bare soil at Davis to be above 60°F from April to November, inclusive, and above 78° during June, July, August, and September. At the 6-inch depth mean monthly soil temperatures were 46°F in December, 49°F in January, and 50°F in February, while at the 2-foot depth they were 55°, 50°, and 52°F, respectively. The soils in Smith's plat were moist nearly to field capacity throughout the year, except in the surface soil which to a depth of 4 to 6 inches was more or less completely dried out.

Mohr (3) has stated that "humus will accumulate between 0°C (32°F) and 25°C (77°F) and will accumulate most between 15°C (59°F) and 20°C (68°F), but between 20°C and 25°C the accumulated surplus is less and less, and above 25°C destruction takes place faster than formation." If this statement can be applied to California conditions as indicated by the soil temperatures obtained by Smith, then "humus" would accumulate in those soils during November, December, January, February, March, and April; be balanced between accumulation and destruction during May and October; and suffer destruction during June, July, August, and September.

Under the summer season conditions of dryness and high temperatures the organic debris appears to be rapidly oxidized and destroyed without the accumulation of much decaying organic matter upon the soil surface or of much organic colloid within the mineral soil. During the wet season temperatures are cool, but not cold, and the soil is rarely, if ever, frozen except at high elevations. The soils become moistened with the early rains of September and October, and remain moist until dried out by the growing vegetation in April or May. Thus, there are, roughly, about six months when the surface soils are dry and warm and six months when they are moist and cool. During the former period oxidation and dry decomposition takes place, while in the latter period of moist conditions bacterial decomposition is active and consequently the destruction of organic matter proceeds throughout the full year. The net result of such conditions would be the formation of soils with a relatively low content of organic matter, and particularly of organic colloids or "humus."

These observations are borne out by the very extensive studies of Hilgard and of Loughridge (2), in which they show the "humus"

[3]Reference by number is to "Literature Cited," p. 576.

content of California soils to be consistently low. The average of the surface soils of the 109 California soil columns which they studied in detail showed 1.35% humus (determined by a modified Grandeau method) and the average of 331 miscellaneous surface soils from California and 44 from Idaho, Arizona, and Oregon 1.28%, while the average of 280 surface soils from humid portions of the United States showed a humus content of 2.63%.

TABLE 1.—*Average percentage of humus in soils of different color.*

Depth, feet	Black lands 17 columns	Gray lands 16 columns	Red lands 10 columns
1	1.19	0.94	0.64
2	0.45	0.69	0.42
3	0.38	0.57	0.28
4	0.26	0.47	0.24
5	0.22	0.44	0.24
6	0.21	0.40	0.17
7	0.15	0.37	0.12
8	0.12	0.30	0.10
9	0.11	0.31	0.11
10	0.09	0.28	0.11
11	0.05	0.25	0.12
12	0.08	0.22	0.18

Where the organic material is accumulated upon the soil, as in forested humid regions of temperate or cold climates, the products of organic decay may be dominant in determining the profile characteristics of the matured soils. This is probably true of podsols and of most podsolic soils. Where, however, surface accumulations of organic debris do not occur, the influence of the organic materials is less pronounced and is evidenced most definitely in the soil color. In the arid regions even this effect on the color is decidedly reduced with all well-drained soils.

Loughridge studied the relations between color and humus content as shown by the analyses of the California soil columns, summarizing his results (Table 1) to show the average percentage of humus in the soils of different colors.

Discussing the relations of humus to color as shown in these columns, Loughridge (2) states,

"It has already been pointed out that a black color does not necessarily mean the presence of a high percentage of humus, and this is again emphasized in the composite columns of many soils of three colors taken from the main agricultural regions of the state. In these the surface foot of the black has but little more humus than that of the gray soil (1.19 and 0.94%, respectively). But still more surprising is the fact that, although the upper 3 feet of the black lands are almost invariably very dark and even black, they contain less humus than the upper 3 feet of the gray sandy lands; and that

throughout the entire composite columns the percentage of humus is greater in the gray than in the black soils with the exception of the first foot....

The composition of 11 red lands embracing mesa and hill lands and the more level lands on the eastern side of the great valley contain less humus than either the black or the gray, except in the lower 6 feet."

EXPERIMENTAL DATA

An endeavor was made to determine the extent to which the organic colloids influence the color of the soil by measuring the original color of the soil and its color after digestion with hydrogen peroxide. It was assumed that the major portion of the organic colloid and other "humified" organic matter would be oxidized and destroyed by the hydrogen peroxide and that the degree of bleaching thus produced would measure the effect of the organic matter on the soil color and particularly on the "blackness" of the soil.

The color measurements were made by use of the rotating disc colorimeter developed by Hutton and others of the Color Standards Committee of the American Soil Survey Association, using the Munsell discs of white (neutral 9), black (neutral 1), yellow (yellow 8/8), and red (red 4/9). The soils, both untreated and treated, were painted onto blotting paper and discs of the dried soil-covered paper mounted as the central portion of the rotating disc during the measurement.

The digestion was made by weighing out 10 grams of soil, moistening with about 5 ml. of water, adding 1 to 1½ ml. of glacial acetic acid (to prevent the catalytic effect of the manganese that was usually present), and 10 ml. of 30% hydrogen peroxide. They were allowed to digest at room temperature for from 12 to 24 hours, then on a hot plate for from 4 to 12 hours, being covered to prevent rapid evaporation.

A representative set of the measurements is shown in Table 2, which gives the color percentages of 12 soils from the Dixon area in Solano County, Calif. The natural colors of the Yolo and Ledgewood types are very similar, but the colors of the treated soils show that there were marked differences in degree of bleaching. The Ledgewood silty clay loam lost 3% of its black, while the Ledgewood fine sandy loam lost 20%. The Yolo silt loam lost 28% and the Yolo fine sandy loam lost 19%.

Table 3 gives certain analyses of these same soils, and shows that there is no correlation between either the initial blackness of the soil or the percentage loss of blackness and any of the other factors determined. The Olcott fine sandy loam, with a nitrogen content of

0.060%, and the Hartley fine sandy loam, with 0.061% nitrogen, are both low in blackness, having 59% and 45% and losing 39% and 29%, respectively. But the Ledgewood silty clay loam, calcareous subsoil phase, blackness 67% and loss 40%, has 0.209% of nitrogen; the Ledgewood silty clay loam, blackness 65% and loss 3%, 0.137% nitrogen; while the Hugo clay loam, blackness 54%, loss 30%, has 0.153% nitrogen. Evidently neither blackness nor degree of bleaching are correlated with the organic content as measured by the nitrogen in the soil.

There is no evident correlation between either initial blackness or bleaching and the content of colloid clay, the total clay, or the moisture equivalent in any of these soils. The nitrogen content was not determined for the other areas, but the same lack of correlation between blackness and clay content, moisture equivalent, reaction values, or other determined factors holds true for all the soils studied.

FIG. 1.—Map showing location of areas studied.

Ten regions in seven soil survey areas were studied in this manner located as shown in Fig. 1, the regions being selected to give diverse precipitation and temperature conditions, coastal and valley climates, and differences in elevation. Three coastal regions were included. The Eureka area lies on the northwest coast of California in the fog belt, with a difference in mean temperatures between the six "summer" months and the six "winter" months of only 4.4°F and with 40 to 45 inches of rainfall. It bears a natural cover of a dense stand of redwood forest. All but one of the samples are from cleared lands. The San Luis Obispo area lies on the central coast, in the fog belt, with a difference of mean temperature of "summer" and "winter" of 6.5°F and a rainfall of from 20 to 25 inches. Both these areas are classed by Russell (4) as Csn (Mesothermal humid) on the Koppen scale. The San Luis Obispo area has a natural cover of scattered oaks and pines with a grass ground cover or of fairly close brush chaparral. Nearly all is now cleared and grass is the usual cover. The Oceanside area is on the south coast (San Diego County) with differences of 6.9°F in mean summer and winter temperatures and with 10 to 14 inches of rainfall. It rarely has fog, but in summer

TABLE 2.—*Color measurements, Dixon area, Solano County, California.*

Soil	Depth, inches	Elevation, feet	White		Black		Yellow		Red		Color
			Natural* H_2O_2	Gain or loss, %	Natural* H_2O_2	Gain or loss, %	Natural* H_2O_2	Gain or loss, %	Natural* H_2O_2	Gain or loss, %	
Valley Plains											
Yolo silt loam	0–15	40	9 12	+33	65 47	−28	16 27	+69	10 14	+40	Brown
Yolo fine sandy loam	0–15	45	8 11	+37	67 54	—19	15 22	+46	10 13	+30	Brown
Ledgewood silty clay loam	0–15	70	10 11	+10	65 63	−3	16 17	+6	9 9	±0	Brown
Ledgewood fine sandy loam	0–14	85	9 10	+11	66 53	−20	15 23	+53	10 14	+40	Brown
Ledgewood silty clay loam, calcareous subsoil phase	0–18	60	10 15	+50	67 40	—40	14 27	+93	9 18	+100	Brown
Oicott fine sandy loam	0–19	80	13 20	+54	59 36	—39	17 25	+47	11 19	+73	Light brown
Averages	—	—	9.8 13.1	+33.6	65 49	—24.6	15.5 23.5	+51.6	9.8 14.5	+47.5	Brown

Valley Foothill Margin

Hugo clay loam	0–10	500	12 15	+25	54 38	—30	24 30	+25	10 17	+70	Grayish brown
Los Osos clay loam	0–10	600	6 7	+17	74 47	—36	11 24	+118	9 22	+144	Dark brown
Hugo fine sandy loam	0–10	380	10 9	—10	58 37	—36	16 25	+56	16 29	+71	Light brown
Denverton adobe clay	0–12	230	7 10	+43	65 36	—45	16 29	+71	12 25	+108	Brown
Esparto silty clay loam	0–15	300	11 14	+27	60 35	—41	17 29	+71	12 22	+83	Light brown
Hartley fine sandy loam	0–18	120	5 5	±0	45 32	—29	22 25	+13	28 38	+36	Reddish brown
Averages	—	—	8.5 10.0	+17.6	59 37	—37.3	17.6 27.0	+53.4	14.5 25.5	+75.8	Brown (light)

*The upper figure gives the percentage of color in the natural soil; the lower figure the percentage of color of the H_2O_2 treated soil.

TABLE 3.—*Soil characteristics, Dixon area, Solano County, California.*

Soil	Depth, inches	Nitrogen %	pH	Moisture equivalent	Sands %	Silt %	Coarse clay, 5μ–2μ, %	Ultra clay, 2μ–1μ, %	Colloid clay, 1μ–0μ, %
				Valley Plains					
Yolo silt loam	0–15	0.124	7.2	23.6	26.08	51.10	8.52	5.49	8.81
Yolo fine sandy loam	0–15	0.096	7.3	18.9	55.86	23.56	6.90	3.03	10.65
Ledgewood silty clay loam	0–15	0.137	7.4	28.6	9.98	43.32	11.19	8.55	26.96
Ledgewood fine sandy loam	0–14	0.103	7.3	21.1	42.19	31.77	7.10	3.99	14.95
Ledgewood silty clay loam, calcareous subsoil phase	0–18	0.209	7.9	29.4	10.84	43.27	14.09	8.12	23.68
Olcott fine sandy loam	0–19	0.060	6.6	13.4	60.09	25.17	5.44	1.94	7.36
Average	—	1.21	7.3	—	—	—	—	—	—
				Valley Foothill Margin					
Hugo clay loam	0–10	0.153	6.5	27.7	8.58	41.41	13.84	8.59	27.58
Los Osos clay loam	0–10	0.108	6.1	24.1	49.58	16.94	7.48	3.05	22.95
Hugo fine sandy loam	0–10	0.064	6.8	16.3	58.75	22.46	5.34	3.33	10.12
Denverton adobe clay	0–12	0.130	7.4	32.0	14.87	24.53	11.35	5.40	43.85
Esparto silty clay loam	0–15	0.112	6.5	22.1	25.63	40.80	9.69	5.44	18.44
Hartley fine sandy loam	0–18	0.061	5.9	16.2	32.22	49.70	7.22	2.08	8.78
Average	—	1.05	6.5	—	—	—	—	—	—

may have a thin high "fog" or haze that materially decreases the intensity of the sun's rays. It is classed by Russell as Bwhn (arid coast desert) in the southwestern part and as Bsh (arid desert steppe) throughout the rest of the area. Both sections of the area have a natural cover of scattered brush with some trees (oaks usually) and with grass and annuals as the ground cover.

The Grass Valley area covers a transect of the Sierra foothills, with elevations from 300 to 4,000 feet. Most of the soils are reddish in color, and by far the larger area is derived from the same or a similar rock—a rather basic andesite. Three years ago a set of special samples was selected to represent soils at different elevations, and from this set the nine samples here reported were selected. All are members of the Aiken series. On the basis of blackness lost they were found to fall into three natural groups, representing low (350 to 800 feet), medium (1,400 to 2,500 feet), and high (2,750 to 3,600 feet) elevations, with annual rainfall of 22, 34, and 52 inches. The two lower regions are classed as Csa (Mesothermal humid) or "olive" climates, while the upper region is designated Csáb, or a "pine-fir" climate. This latter region has a natural cover of Douglas fir, sugar pine, and incense cedars in moderately dense stands. The mid-elevation region has a cover of rather open forests of oak and "digger" pine with a ground cover of grass and herbs, while the lower elevations have open or scattered oaks and occasional pines with the main cover grass and herbs.

The Dixon area covers northern Solano County, in the Sacramento Valley, and has been studied in two sections, the western valley margin or foothill portion with a climate (Vacaville) showing 26 inches of rainfall and the valley plains portion (Davis) with rainfall of 17 inches. The natural cover of the former was scattered oaks and digger pines with a ground cover of grass and herbs, while that of the latter portion was grass and herbs. Both portions are included in the Csa "olive" climate.

The Coalinga region represents one of the driest and hottest parts of the Upper San Joaquin Valley, receiving about 7 inches of rain, a mean annual temperature of over 62°F and a mean range between the six "summer" months and the six "winter" months of over 20°F. It is classed as Bwh (arid hot desert) and has a natural cover of sparse winter-growing grasses and herbs and a few scattered perennial desert shrubs. The El Centro area lies in the Imperial Valley with rainfall from 2 to 4 inches, and is classed as Bwhh (arid very hot desert). It bears a very sparse cover of scattered brush and, after the occasional rains, short-lived desert annuals.

Table 4 gives the average blackness and the average percentage loss after H_2O_2 treatment of the soils from each of these regions, the color of this "average" soil (from the color analysis), the calculated "rain-factor" of Lang$\left(\frac{\text{precipitation in mm}}{\text{temperature in °C}}\right)$, and, for some stations where the necessary data were available, the absolute saturation deficit or "NSQ" of Meyer calculated by the formula presented by Jenny (1).

A study of Table 4 shows that the soils from desert areas, Upper San Joaquin Valley and El Centro, have the lowest total blackness and the lowest percentage of blackness lost. (The six soils from the El Centro area showed no loss of blackness whatever, although chemical determinations of carbon in two of these soils showed 2.02% and 2.05% total, 1.63% and 1.54% carbonate carbon, and 0.39% and 0.51% organic carbon, respectively.) The soils of the desert areas are distinctly lighter in color and lower in organic matter than those of the more humid areas. Beyond this generalization, however, we cannot go.

A study of the three coastal areas shows the San Luis Obispo area, with intermediate climatic conditions, to have more blackness and to lose a higher percentage of the black than either the Eureka area, with twice the rainfall (rain-factor and NSQ tripled), or the Oceanside area with half the rainfall (about one-half rain-factor and NSQ).

A study of the Grass Valley soils shows that the combined effects of elevation, rainfall, and temperature are similarly inconclusive. While the soils at the highest elevations had most blackness (61%) they lost only 10%. The blackness of the lowest soils (53.3%) was slightly more than those at the intermediate elevation (51.3%), but they lost only 4% as compared to 30% for the intermediate soils. Similar results were obtained from the Dixon area where rainfall is the variable and where the valley margin with a rainfall of 26 inches had a blackness of 59% and lost 37% and the valley plains with a rainfall of 17 inches had a blackness of 65% and lost 25%. The results are not only inconclusive but contradictory.

These studies show no evidence of correlation between the measured color characteristics of the soil and the climatic factor of total annual rainfall or of winter season rainfall. Neither is there any correlation with the factors that endeavor to integrate the temperature and humidity with rainfall—the "rain-factor" or the "absolute saturation-deficit" or NSQ. We are forced to conclude from these results that, while there appear to be broad, generalized relations between the blackness of the soils and the bleaching or loss of this blackness that

TABLE 4.—*Climate, vegetation, and average blackness of soils in 10 locations.*

Area and location	Elevation, feet	Precipitation, inches		Temperature, °F		Climate	Cover	Rain factor Lang	N.S.Q. Meyer	Average color	Blackness	
		Summer* Winter	Annual	Summer* Winter	Annual						Natural† H_2O_2	Gain or loss, %
Eureka, northwest coast	50 to 150	7.60 34.25	41.85	53.9° 49.5°	51.7°	Csn	Redwood forest, cleared	92.2	549	Yellowish brown	68.75 51.00	—26.0
San Luis Obispo, central coast	50 to 1,200	2.96 17.65	20.61	61.7° 55.2°	58.5°	Csn	Open, oak and grasslands	34.8	±190	Dark grayish brown	73.20 49.07	—33.0
Oceanside, south coast	100 to 950	1.32 8.98	10.30	64.4° 57.5°	60.9°	Bsh and Bwhn	Grass and brush	20.7	81	Dark reddish brown	64.6 45.5	—29.0
Grass Valley, upper Sierra foothills	2,750 to 3,600	8.11 43.61	51.72	65.2° 47.6°	56.4°	Csáb	Pine and cedar	96.9	—	Dark red	61.6 54.3	—10.0
Grass Valley, mid-Sierra foothills	1,400 to 2,500	5.12 28.63	33.75	68.7° 50.9°	59.8°	Csa	Oak and pine	55.5	—	Red	51.3 35.6	—30.0
Grass Valley, lower Sierra foothills	350 to 800	3.28 18.91	22.19	70.5° 51.7°	60.2°	Csa	Oak and grass	35.9	—	Red	53.3 50.6	— 4.0
Dixon, Sacramento Valley margin	120 to 600	3.54 23.01	26.55	67.6° 52.5°	60.0°	Csa	Oak, pine, grass	43.5	—	Brown (light)	59.0 37.0	—37.0
Dixon, Sacramento Valley plains	40 to 85	2.21 14.82	17.03	67.8° 50.8°	59.3°	Csa	Grass, scattered oaks	28.6	102	Brown	65.0 49.0	—25.0
Upper San Joaquin, San Joaquin valley margin	230 to 1,200	1.05 6.19	7.24	72.8° 52.7°	62.8°	Bwh	Sparse grass	10.7	± 25	Light yellowish gray	49.7 46.2	— 7.0
El Centro, Imperial Valley plains	—42 to +26	0.92 2.80	3.72	82.9° 60.8°	71.9°	Bwhh	Desert, sparse shrub	2.3	—	Light purplish gray	40.5 40.5	±0

*The "Summer" precipitation is the total for the six months of April to September, inclusive, and the temperature is the mean for those months. "Winter" is the total rainfall and mean temperature for the months of October to March, inclusive.

†The upper figure gives the percentage of black in the natural soil; the lower figure that in the H_2O_2 treated soil.

may be ascribable to the organic matter content and to the causal factors of climate and vegetation, these relations do not hold when subjected to close study with narrow differences in climatic conditions.

The method of measuring organic effect, digestion with hydrogen peroxide, may be open to criticism, but this alone cannot be held responsible for the lack of correlations. There are evidently other factors influencing the darkness or "blackness" of soil color besides the organic matter. This can be illustrated by two soils of the San Luis Obispo area on which carbon determinations have been made. The Zaca clay loam, blackness 81%, loss 5%, had 2.59% total carbon, 1.36% carbonate carbon, and 1.23% organic carbon, while the Cayucos clay adobe, blackness 79%, loss 30%, had 1.89% total carbon, 0.01% carbonate carbon, and 1.88% organic carbon. From the Eureka area the Rhonerville silt loam, blackness 84%, loss 38%, had 3.09% carbon, all organic, and the Empire loam, blackness 61%, loss 20%, had 1.14% carbon, all organic. The Zaca clay loam of the San Luis Obispo area and the Empire loam of the Eureka area have more or less similar climate environments, yet with the former 1.23% organic carbon accompanies a blackness of 81%, while with the latter 1.14% organic carbon accompanies only 61% blackness. The former lost only 3% of its blackness when digested with H_2O_2, the latter 20%.

CONCLUSIONS

We must conclude from these studies that the organic matter content is not dominant in determining the color of the soils in regions of periodic precipitation with hot dry summers and cool moist winters, and that it occupies a very minor place in determining the characteristics of soil profiles. Of much more importance in profile development, and consequently to soil classification, are the mineralogical composition of the parent material, the degree of oxidation of the metals, especially iron, the intensity and duration of leaching, and the extent of downward migration and subsoil accumulation of colloidal clays and cementing materials.

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FURTHER STUDIES ON SOIL RESPIRATION[1]

F. B. SMITH and P. E. BROWN[2]

Lundegardh[3] defined soil respiration and proposed a method for its determination. The procedure consisted in placing a conical zinc bell over the soil and allowing the carbon dioxide to accumulate in it. The concentration of carbon dioxide in the bell was determined as soon as the bell was in position and again after a respiration period of 20 to 30 minutes. The amount of carbon dioxide evolved was then calculated. It is obvious that as the carbon dioxide accumulates in the bell the rate of diffusion will be retarded, due to the decrease in the pressure gradient between the concentration of carbon dioxide in the soil and that in the bell, the rate of decrease depending upon the size of the bell, the concentration of carbon dioxide in the soil, and the rate of its production. Lundegardh concluded, however, that the rate of diffusion was proportional to time, when the respiration period was not longer than 20 to 30 minutes.

Humfeld[4] used a rectangular box placed over the soil, and in order to avoid decreasing the rate of diffusion by the accumulation of carbon dioxide under the box, swept air by aspiration over the soil surface.

Smith and Brown[5] have recently concluded that respiration is not a simple diffusion of carbon dioxide through the soil and evolution at the surface, but that it is also a function of the diffusion velocity, adsorption, utilization, solution, and combination. The purpose of this paper is to present further data secured in the study of soil respiration.

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Also presented at the annual meeting of the Society held in Chicago, Ill., November 20, 1931. Journal Paper No. B 20 of the Iowa Agricultural Experiment Station. Received for publication December 3, 1931.

[2]Research Associate Professor and Head of Department, respectively.

[3]LUNDEGARDH, H. Carbon dioxide evolution of soil and crop growth. Soil Science, 23: 417–453. 1927.

[4]HUMFELD, H. A method for measuring carbon dioxide evolution from soil. Soil Science, 30: 1–11. 1930.

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EXPERIMENTAL

If the accumulation of carbon dioxide under a respiration bell, such as the one used by Lundegardh, is a factor of significance in the determination of soil respiration, it would be shown by a comparison of the respiration of a given soil by the Lundegardh method and the method Humfeld used. The respiration of a typical Carrington loam was determined by the titrametric method proposed by Humfeld and a comparison made with the respiration determined by the Lundegardh method.

A Lundegardh respiration bell was used in the determination of the respiration by the two methods. The bell was fitted with two glass tubes, one of which reached to the surface of the soil on one side of the bell and extended 1 meter above the surface of the soil. This tube served as an inlet for the entrance of air into the bell and for the determination of carbon dioxide in the atmosphere. The other tube extended from the surface of the soil on the opposite side of the bell to the absorption unit. A side-tube was introduced at the top of the bell for taking samples of the air in the bell for volumetric analysis.

The procedure followed consisted in drawing 5 liters of air by aspiration through the bell at the rate of 5 liters per hour and absorbing the carbon dioxide in a 0.05 N potassium hydroxide solution. The amount of carbon dioxide taken up was determined by titrating the excess potassium hydroxide with standard acid after precipitating the carbonate with barium chloride.

After making a determination by aspiration, the absorption unit was detached, the bell removed and aerated, and then carefully replaced in the same location for a determination of the respiration by the Lundegardh method. The concentration of carbon dioxide in the bell was determined as soon as it was placed in position and again after a respiration period of 30 minutes, using a portable Haldane volumetric gas analysis apparatus. The respiration was then calculated for the two methods. The results secured from four comparative tests are presented in Table 1.

TABLE 1.—*A comparison of methods for determining soil respiration.*

Test No.	Grams CO_2 per square meter per hour	
	Volumetric method (Lundegardh)	Titrametric method (Humfeld)
1	0.0146	0.0170
2	0.0152	0.0205
3	0.0217	0.0117
4	0.0267	0.0044

The results secured in these tests do not indicate any advantage of the aspiration method and since the volumetric method is simpler than the titration method, no further comparisons of the two methods were made.

The respiration of the same soil was determined 12 times during the month of August and once in September, using the Lundegardh method in the attempt to determine the effect of the accumulation of carbon dioxide under the respiration bell on the rate of carbon dioxide evolution from the soil. The concentration of carbon dioxide in the respiration bell was determined as soon as the bell was placed over the soil and at intervals of 10 to 30 minutes for 1 to 1½ hours. The respiration was calculated for each respiration period and for the total time from the beginning to the end of each respiration period. The results secured are presented in Table 2.

TABLE 2.—*Influence of length of respiration period on rate of respiration.*

Date	Reading	Length of respiration period in minutes	CO_2 in bell air, %	Grams CO_2 per sq. M. per hour for each period	Total time of respiration from beginning, minutes	Grams CO_2 per sq. M. per hour respiration period, total time
Aug. 3	a	0	0.08	——	—	——
	b	10	0.08	0.000	10	0.000
	c	10	0.13	0.065	20	0.032
	d	10	0.10	——	30	——
	e	10	0.19	0.078	40	0.061
	f	10	0.20	0.026	50	0.060
	g	10	0.21	0.026	60	0.056
	h	10	0.30	0.116	70	0.111
Aug. 5	a	0	0.02	——	—	——
	b	30	0.18	0.181	30	0.181
	c	20	0.22	0.052	50	0.105
	d	25	0.30	0.081	75	0.098
	e	30	0.32	0.017	105	0.071
	f	20	0.33	0.013	125	0.068
Aug. 6	a	0	0.09	——	—	——
	b	20	0.12	0.039	20	0.039
	c	15	0.19	0.123	35	0.075
	d	20	0.21	0.026	55	0.058
	e	35	0.26	0.038	90	0.050
Aug. 7	a	0	0.06	——	—	——
	b	20	0.12	0.067	20	0.067
	c	20	0.16	0.053	40	0.066
Aug. 10	a	0	0.10	——	—	——
	b	20	0.12	0.028	20	0.028
	c	20	0.12	0.000	40	0.014
	d	20	0.12	0.000	60	0.009

TABLE 2.—*Continued.*

Date	Reading	Length of respiration period in minutes	CO_2 in bell air %	Grams CO_2 per sq. M. per hour for each period	Total time of respiration from beginning, minutes	Grams CO_2 per sq. M. per hour respiration period, total time
Aug. 21	a	0	0.08	—	—	—
	b	20	0.10	0.026	20	0.026
	c	20	0.12	0.026	40	0.026
	d	20	0.19	0.095	60	0.045
	e	20	0.22	0.040	80	0.046
Aug. 21	a	0	0.07	—	—	—
	b	20	0.11	0.053	20	0.053
	c	20	0.19	0.106	40	0.080
	d	20	0.22	0.040	60	0.049
Aug. 22	a	0	0.04	—	—	—
	b	20	0.08	0.055	20	0.055
	c	20	0.09	0.013	40	0.034
	d	20	0.02	0.178	60	0.080
	e	20	0.24	0.027	80	0.068
Aug. 24	a	0	0.06	—	—	—
	b	10	0.34	0.810	10	0.810
	c	10	0.42	0.235	20	0.480
	d	10	0.43	0.029	30	0.330
	e	10	0.47	0.118	40	0.212
	f	20	0.60	0.079	60	0.220
	g	20	0.65	0.030	80	0.197
	h	20	0.66	0.006	100	0.161
Aug. 25	a	0	0.09	—	—	—
	b	10	0.16	0.152	10	0.152
	c	10	0.31	0.415	20	0.216
	d	10	0.32	0.277	30	0.212
	e	10	0.40	0.221	40	0.165
	f	20	0.43	0.210	80	0.117
Aug. 26	a	0	0.08	—	—	—
	b	10	0.10	0.055	10	0.055
	c	10	0.11	0.027	20	0.041
	d	10	0.17	0.164	30	0.080
	e	10	0.19	0.055	40	0.075
	f	20	0.20	0.013	60	0.055
Aug. 27	a	0	0.10	—	—	—
	b	10	0.12	0.053	10	0.053
	c	10	0.12	0.000	20	0.027
	d	10	0.12	0.000	30	0.017
	e	10	0.13	0.027	40	0.020
	f	20	0.17	0.053	60	0.031
Aug. 27	a	0	0.05	—	—	—
	b	10	0.17	0.323	10	0.323
	c	10	0.12	0.000	20	0.094
	d	10	0.12	0.000	30	0.063
	e	10	0.08	0.000	40	0.020
	f	20	0.06	0.000	60	0.004

TABLE 2.—*Concluded.*

Date	Reading	Length of respiration period in minutes	CO_2 in bell air %	Grams CO_2 per sq. M. per hour for each period	Total time of respiration from beginning, minutes	Grams CO_2 per sq. M. per hour respiration period, total time
Sept. 4	a	0	0.04	——	—	——
	b	10	0.10	0.158	10	0.158
	c	10	0.13	0.079	20	0.118
	d	10	0.14	0.026	30	0.088
	e	20	0.16	0.026	50	0.063
	f	20	0.18	0.026	70	0.053

The results for August 3 show that there was no respiration during the first 10-minute period and that during the third interval there was actual diffusion of carbon dioxide down into the soil. The highest rate of respiration occurred during the 60- to 70-minute period. On August 5, the highest respiration rate was found during the first 30 minutes. Again, on August 24, the highest respiration was found during the first 10 minutes, being about one-fourth as great for the second 10 minutes. In the third 10-minute period the respiration rate decreased, being about one-tenth as high as that found in the second period. The respiration was 0.053 gram of carbon dioxide per square meter per hour during the first 10-minute period on August 27. During the second and third respiration periods there was no diffusion of carbon dioxide. During the fourth 10-minute interval the respiration rate was about one-half as great as during the first period and during the 40- to 60-minute period the rate was the same as during the first respiration period.

Again, on August 27, during the first 10-minute respiration period, the concentration of carbon dioxide in the bell increased 0.12%, during the second 10 minutes it decreased 0.05%, and it was not changed during the third interval. The decrease was 0.04% for the fourth period and 0.02% for the 40- to 60-minute period. The results secured on September 4 show a respiration of 0.158 gram of carbon dioxide per square meter per hour for the first 10 minutes, 0.079 gram for the second 10 minutes, and 0.026 gram for the third 10 minutes. The rate of respiration was constant for the next 40 minutes.

It is evident from these data that several factors influence the respiration. For example, it was noted that in some cases there was a negative respiration, that is, carbon dioxide diffused downward. This point is emphasized in the following experiment.

Two tubes were planted in the soil earlier in the year to study

the concentration of carbon dioxide in the soil at different depths. One tube was placed 14 inches deep and the other 8 inches deep immediately above the first. About 2 months later a respiration bell was placed over the two soil tubes. Two glass tubes were introduced in the top of the bell to sample the air at the surface of the soil and 6 inches above the surface of the soil. Seven readings were taken from each of the tubes over a period of 10 days. The results appear in Table 3.

TABLE 3.—*The concentration of carbon dioxide in the soil air at different depths.*

Date	Percentage carbon dioxide			
	12–14 inches	6–8 inches	Soil surface under respiration bell	6 inches above soil surface under respiration bell
Aug. 10	0.99	0.51	0.04	0.09
Aug. 11	0.77	0.52	0.16	0.12
Aug. 13	1.08	0.74	0.28	0.26
Aug. 18	1.13	0.89	0.44	0.47
Aug. 19	0.87*	0.61	0.18	0.21
Aug. 20	0.97	0.78	0.38	0.29

*Rain night of Aug. 18.

The data in the table show that the carbon dioxide diffused upward, increasing the concentration in the surface soil and in the respiration bell. They also indicate that carbon dioxide diffused downward when the concentration in the surface soil was greater than the concentration in the sub-surface. A light rain on the night of August 18 undoubtedly removed a large part of the carbon dioxide in the soil air. After the rain the cycle of carbon dioxide production and diffusion began again.

Lundegardh took samples of soil at various depths and determined the amount of carbon dioxide evolved in closed flasks. The profile was then reconstructed and the total average production was found to be very nearly the same as the average rate of respiration.

In the work reported here samples of Carrington loam were taken at the 0 to 15 cm, 15 to 20 cm, and 20 to 35 cm depths. The average rate of production was determined in closed flasks by a method similar to the one employed by Lundegardh. The results appear in Table 4.

The average production in the 0 to 15 cm layer of soil was 0.566 gram of carbon dioxide per square meter per hour, that of the 15 to 20 cm layer 0.044 gram per square meter per hour, while there was a loss of carbon dioxide in the air in the flask containing the soil from the 20 to 35 cm depth. The total average production was 0.610 gram

TABLE 4.—*Carbon dioxide production in the profile and the respiration of Carrington loam.*

Depth in cm	Grams CO_2 per square meter per hour (production)
0–15	0.5660
15–20	0.0435
20–35	——*
Total average production	0.6095
Grams CO_2 per square meter per hour (respiration)	0.1580

*There was less carbon dioxide in the flask with this soil after 18 hours than there was in the beginning.

per square meter per hour. The respiration of this soil *in situ* was only 0.158 gram per square meter per hour.

SUMMARY AND CONCLUSIONS

The rate of respiration in a typical Carrington loam was determined by titrametric and volumetric methods. The data secured showed no apparent relation between the determinations by the two methods.

The rate of respiration during several successive periods was determined by the Lundegardh method. It was found that some other factor than rate of diffusion had an influence on the rate of respiration.

The concentration of carbon dioxide in different layers of the soil under the respiration bell indicated that diffusion may be downward and that this downward diffusion, together with the solution of carbon dioxide and its removal in drainage water, influence the rate of respiration.

The average rate of production of carbon dioxide by soil from various depths and the total production for the profile were determined for comparison with the rate of respiration. It was found that the greatest production occurred in the surface and that adsorption took place in the sub-surface soils. The total production was found to be much greater than the rate of respiration, even when allowance was made for the adsorption by the sub-surface soil.

These results confirm the conclusion that soil respiration is not a simple diffusion of carbon dioxide through the soil and can not be regarded as an accurate measure of the rate of carbon dioxide production in the soil.

NOTES

FLORET STERILITY IN WHEAT CAUSED BY A LATE SPRING FREEZE

A snowstorm accompanied by temperatures as low as 27°F in central and western Kansas on May 21 and 22, 1931, was apparently responsible for an unusual type of floret sterility which occurred in certain varieties of wheat grown in cooperative tests with farmers. Approximately 50 of these cooperative varietal tests in as many different locations were examined and an estimate made of the injury sustained in each case.

There was no noticeable injury to the awns, glumes, leaves, or culms of the plants. In some cases the sterility was slight, only occasional heads showing sterile florets. In other cases the injury was severe, many heads being observed in which all of the florets were sterile and others with varying degrees of sterility. As the grain

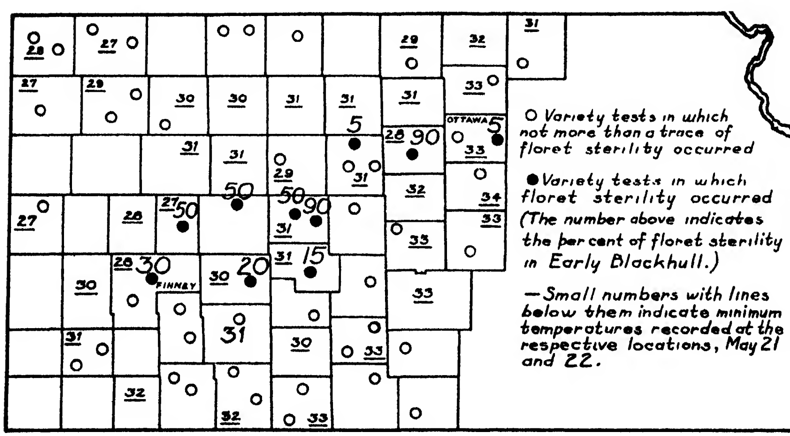

FIG. 1.—Map showing the relationship of late minimum temperatures to floret sterility in an early selection of blackhull wheat in Kansas in 1931.

developed in the fertile florets, the affected heads took on a ragged, irregular appearance that was noticeable at a considerable distance. The proportion of sterile florets in the different varieties varied directly with their earliness in maturity, being as high as 90% in Early Blackhull, a variety which normally heads and ripens a week to 10 days earlier than Turkey. The sterility was always less in other varieties.

Fig. 1 shows (1) the location of the variety tests in central and western Kansas, (2) the location of those tests in which the sterility in Early Blackhull was 5% or more, and (3) the minimum temperature recorded by the nearest weather bureau station for the 2-day period, May 21–22.

It will be noted that practically all of the floret sterility occurred in an area about two counties wide, extending across central-western Kansas in a southwesterly direction. The minimum temperatures in this area ranged from 27° to 31°F. Minimum temperatures from

27° to 31° prevailed over the northern and western parts of the state also, but no more than a trace of floret sterility was observed. The explanation no doubt lies in the fact that none of the varieties, including the Early Blackhull, were in head at the time, whereas in the affected area the Early Blackhull had just headed and the others were beginning to head when the freeze occurred. Thus, evidence is lent to the theory that the floret sterility was caused by freezing injury to some delicate part of the wheat flowers at a particular stage of development. The fact that some florets were sterile while others on the same head and sometimes in the same spikelet developed normal kernels indicates that the wheat flower remained for only a very short time in the stage which was most susceptible to freezing injury.

The type of floret sterility described here is very unusual in Kansas. However, it may be an important factor in the future in connection with the development of extremely early varieties of wheat which, though possibly more desirable from the viewpoint of escaping drouth and hot winds, may be in more danger of being overtaken in the heading stage by freezing temperatures.—F. L. TIMMONS and A. L. CLAPP, *Kansas State College of Agriculture, Manhattan, Kans.*

SIMPLIFIED EQUIPMENT FOR ROD ROW THRESHER

At the summer meeting of the Corn Belt Section of the American Society of Agronomy held at Purdue University in June 1931, much interest was shown in the threshing and cleaning equipment used in the plant breeding work in the Agronomy Department. A number of agronomists and plant breeders have requested the specifications of this equipment, hence a short description will be given.

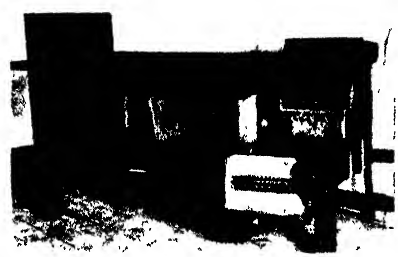

FIG. 1.—The thresher with the casing open, showing the cylinder and concave.

Instead of combining both thresher and blower in one machine, two separate pieces of equipment have been designed and built. In doing so an attempt has been made to effect economy, simplicity, and increased efficiency, with a minimum of danger of mixing.

ROD ROW THRESHER

Briefly, the thresher consists of a 15½-inch over-shot cylinder, 7¼ inches in diameter. It is built into a wooden casing which is supported by a 13-inch base. The interior of the cylinder casing is constructed so that lodgement of grain is impossible. This also enables the machine to clean itself completely. The upper half of the casing enclosing the cylinder is hinged at one side (Fig. 1) so that it can be opened and the cylinder and concave exposed. The base on which the cylinder is supported is high enough to admit of

a suitable receptacle being placed directly beneath the cylinder to catch the threshed grain and chaff. The straw does not pass through the cylinder. Furthermore, there is no loss of grain since all of it passes directly into a receptacle below. The receptacle is made of galvanized iron.

The cylinder has been built so ruggedly and simply that a rod row can be threshed without allowing the straw to pass through (Fig. 2). This avoids loss of grain which often occurs in threshing and also obviates difficulties which often arise in making a satisfactory separation of grain from chaff and other refuse.

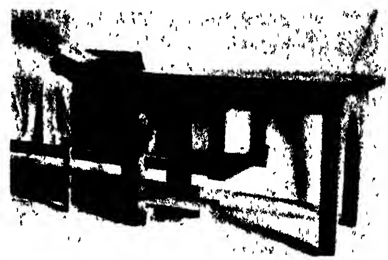

FIG. 2.—Thresher and table to which motor is also attached.

For convenience, the frame which supports the cylinder is attached to one end of a well-made heavy table of the same height as the cylinder and 58½ inches long. The ½ h. p. motor which is used to drive the cylinder is attached to and under the table but out of the way of the operator The table is used as a convenient place to weigh and untie the rod row sheaves, preparatory to threshing.

THE BLOWER-SEPARATOR

A blower-separator has been designed with the single object of separating the grain from the chaff, pieces of straw, etc., with no possibility of mixing. It consists of two parts, *viz.*, the blower consisting of an 18 inch electric fan and a galvanized iron casing which merely confines and directs the air blast. The electric fan is standard equipment and can be purchased at any electric supply shop.

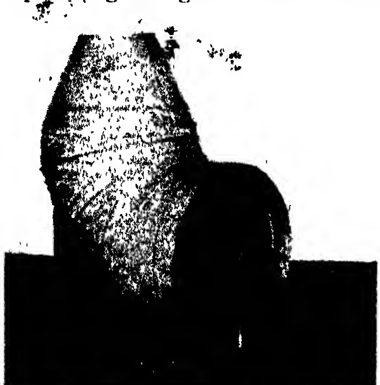

FIG. 3.—Blower-separator, consisting of an elbowed galvanized casing, and an 18-inch electric fan.

The galvanized iron casing was made by a local tinsmith. It is 18 inches in diameter and elbowed with the upper section constricted to 8½ inches so as to concentrate the air blast (Fig. 3). This casing is fastened to a wooden frame which holds it in an upright position. The blower or electric fan sits on the floor and fits snugly into the lower section of the casing. The fan is equipped with three speeds, hence the strength of the air blast can be modified to suit the needs of the operator.

It will be seen that the operation of these two pieces of equipment is simple. As the grain is threshed, it and the chaff, etc., but not the straw, pass down into a galvanized receptacle directly below the cylinder. The receptacle, in turn, is equipped with a tray which fits into the upper part. The tray is 18 inches in diameter and screened so that part of the chaff and pieces of straw are retained and the grain passes thru into the receptacle. The contents of the receptacle are then poured into another screened tray. The separation of grain from chaff is then made by simply holding the screened tray in the air blast at the upper end of the galvanized casing. Accordingly, no mixing is possible since the grain remains in the tray, while the chaff is blown away.

With these two pieces of equipment it is possible to insure absolute purity, if average care is exercised, since there is no place in the equipment where grain can lodge and carry over from plat to plat. Hence, the seed can be used from season to season, thus obviating the necessity of selection plats as are sometimes used for seed purposes. This equipment can be used as well for smaller or larger lots than rod rows.

Both pieces were built locally at a cost of less than $75.00. The electric fan costs about $20.00.

Last season three men were able to weigh, thresh, and clean, on an average, 161 rod rows in an 8-hour day, based on 9 days continuous threshing. This gives some idea of the speed with which threshing and cleaning can be done. A blue print and specifications of these pieces of equipment will be furnished to any experimentalist upon request.

The writer desires to thank F. N. Jones for assistance in designing and building the thresher; Claude Greenham, of the Agronomy Department, for designing the galvanized casing for the blower; and M. K. Lyon, mechanical engineering student, for drafting the plans.—G. H. CUTLER, *Purdue University, Lafayette, Indiana.*

BOOK REVIEW

A BIBLIOGRAPHICAL LIST OF THE ENTIRE DOMAIN OF AGRICULTURAL CHEMISTRY

Edited by H. Niklas and A. Hock. Munich: Agricultural-Chemical Institute Weihenstephan of the Technical University of Munich. 1931. Vol. I. Soil Science, by H. Niklas, F. Czibulka (compiler), and A. Hock. XXXVIII + 1008 pages. $9.60. Vol. II. Soil Analysis, by H. Niklas, F. Czibulka (compiler), and A. Hock. XXX + 199 pages. $3.00. Title, prefaces, and tables of contents in both German and English.

As the title indicates this is an extremely ambitious piece of work on the part of Prof. Niklas and his collaborators. In fact the two volumes just published are a part of a still larger bibliographical program on the part of the same authors which is to include volumes on Plant Nutrition, Fertilization, Agricultural Bacteriology, and Animal Nutrition and Feeding Teaching. As stated in the preface of Vol. I, it is significant and indicative of peculiar abilities and forces

in the German nation when under calamity, that such a work has appeared at this time.

The work is well printed with the authors' names in alphabetical order and in heavy type which makes any desired title easily found. Both a subject and author index add further to the convenience and speed of finding desired sources.

For the most part the references to the soils literature of English-speaking countries is printed in English, the others in German. Vol. I is divided into eight sections, as follows: General literature, formation of soils, soil chemistry, soil physics, relations between soil and surroundings, classification, soils of different countries, and composition of soils, rocks, and minerals.

Vol. II is divided into analysis in general, sampling, chemical analysis, physical analysis, microbiological analysis, microscopic analysis, and analysis of rocks. Although it is impossible, without great labor, to determine how thorough the work has been done, a casual examination indicates a surprising amount of bibliographical research.

The books should be a great aid to all soils workers who wish to examine the literature of soils and should greatly shorten the otherwise time-consuming task of getting in touch with published work. Along with the abstract journal, the bibliographical index, if well done, forms an important modern tool which greatly conserves the time and energy of the busy teacher or research worker. All soils workers should, therefore, be especially appreciative of this almost collossal undertaking of Prof. Niklas and his collaborators. (R. C. C.)

AGRONOMIC AFFAIRS

NEWS ITEMS

Announcement has been made of the formation of the Potash Company of Canada, Ltd., which is to take over for the Dominion of Canada all phases of the potash business heretofore conducted from New York City by the N. V. Potash Export My., Inc., of Amsterdam, Holland. In addition to its commercial activities, the new organization will continue the agricultural and educational work of the N. V. Potash Export My. H. E. Lefevre of Montreal is General Manager of the new enterprise.

The Proceedings of the Second International Congress of Soil Science may now be ordered direct from Dr. D. J. Hissink, 122 Verlengde Oosterweg, Groningen, Holland. The price to members of the International Society of Soil Science is $10; to non-members, $20.

H. W. Warner, formerly connected with the National Fertilizer Association and the Barrett Company, died suddenly last month. Mr. Warner will be remembered, among other things, for his assistance in leading the singing at the annual meetings of the Society.

Because of unfavorable financial conditions, the annual summer meeting of Southern Agronomists, which was to have been held in Virginia in August this year, has been indefinitely postponed until such time as general conditions will permit of a resumption of the meetings.

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REACTION AND CALCIUM CONTENT OF DRAINAGE WATER FROM PEAT DEPOSITS IN NEW YORK[1]

B. D. WILSON, E. V. STAKER, and G. R. TOWNSEND[2]

A chemical study which was restricted to virgin peat soils of the cultivated areas of New York showed the soils to be acid in reaction and relatively high in calcium. Some of the soils, having hydrogen-ion concentrations of pH 5.5 or less, were found to contain as much as 6% of calcium oxide. This relationship led to an examination of the drainage waters from a number of peat deposits to ascertain the reaction and the calcium content of water that had percolated through the upper zone of peat soil acid in reaction and of high calcium content.

COLLECTION OF DRAINAGE WATER

Three methods were used to collect the drainage water from the peat soils of the investigation. In most cases the water was taken from lateral drainage ditches near the center of large tracts of cultivated peat soil. The ditches were usually about 2½ feet deep. At such locations there was no chance for the drainage water to be contaminated by that from the upland. A few of the samples were collected as the water issued from the peat deposit at depths of approximately 2½ feet. Two of the samples were taken from the surface of floating bogs composed chiefly of sphagnum moss.

NATURE OF THE PEAT DEPOSITS

The waters which were collected were representative of the drainage from peat deposits derived from many kinds of vegetation. The dominant character of the material comprising the part of the deposit

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication December 10, 1931.

[2]Assistant Professor of Soil Technology, Research Instructor in Soil Technology, and Assistant, respectively.

above the position at which the water was collected is recorded in Table 1. The substances which are characteristic of the upper 3 feet of the deposits are wood, reed, sedge, cat-tail, and sphagnum moss. These occur in the different deposits in varying amounts and in various combinations.

REACTION AND CALCIUM CONTENT OF THE WATERS

The reaction of the drainage waters was determined potentiometrically, using a quinhydrone electrode. Calcium in the water was determined gravimetrically by means of the ammonium oxalate method. The results of the analyses are shown in the last two columns of Table 1, which shows also the reaction and the calcium content of the surface foot of the soils through which the waters percolated. The values for the second foot of soil do not differ materially from those for the first foot of soil and for that reason they are not presented in the table.

If the reactions of the waters from the peat soils of sphagnum origin are excepted, all of the waters, but two, are shown to be alkaline and to have passed through acid peat. No correlation, however, appears to exist between the alkalinity of the water and the acidity or the calcium content of the soil through which it percolated. For example, the alkalinity of the waters from stations 4, 5, and 6 is identical, yet the corresponding soils differ with respect to reaction and to calcium content.

The waters from stations 9 and 10 were found to be acid in reaction. They are shown to be associated with soils relatively high in acidity and low in calcium. These soils are underlain with non-calcareous material. The waters of alkaline reaction are shown to have been collected from soils underlain with either shell or chara marl or with calcareous clay. This relationship of reaction to the presence or absence of carbonate in the underlying stratum suggests that the nature of the material underlying the peat deposit influences the reaction of the drainage water from the upper few feet of the peat soil.

Water taken from organic deposits containing sphagnum were found to be acid. The water at station 18, the peat soil at which is derived from reed and sedge as well as from sphagnum, was found to be less acid than were the waters collected from the sphagnum bogs in Herkimer and St. Lawrence Counties. The soil at station 18 rests on non-calcareous sand and the soil of the deposit is very acid. Under such conditions it is interesting to note that the drainage water from the soil is not more acid than pH 6.9.

TABLE 1.—*The reaction and calcium content of drainage water from peat soils and the relation of these qualities to the character of the peat deposit.*

No. of station	Location (County)	Type of deposit	Depth in feet	Underlying material	Soil		Water	
					pH	CaO, %	pH	Ca, p.p.m.
1	Wayne	Wood, reed	7	Chara marl	6.2	7.9	7.3	70
2	Madison	Wood, reed	5	Chara marl	5.6	6.0	7.6	73
3	Madison	Wood, reed	4	Chara marl	5.2	6.5	7.2	238
4	Wayne	Wood, reed	7	Calcareous clay	6.4	6.1	7.6	73
5	Oneida	Wood, reed	10	Calcareous clay	5.8	5.3	7.6	76
6	Oneida	Wood, reed	5	Calcareous clay	5.7	3.7	7.6	71
7	Orange	Wood, reed	7	Calcareous clay	5.9	7.3	7.5	41
8	Oswego	Wood, reed	10	Calcareous sand	5.2	4.4	7.2	59
9	Wayne	Wood, reed	4	Non-calcareous sand	3.9	0.9	6.0	23
10	Oswego	Wood, reed	3	Non-calcareous sand	4.6	2.1	6.6	62
11	Madison	Wood, sedge	4	Chara marl	6.2	—	7.4	113
12	Orleans	Wood, reed, sedge	6	Shell marl	6.3	6.2	7.2	50
13	Orange	Wood, reed, sedge	17	Chara marl	5.6	4.5	7.5	60
14	Orleans	Wood, reed, sedge	4	Calcareous clay	5.4	6.0	7.2	302
15	Cayuga	Cat-tail, reed, sedge	2	Chara marl	5.5	3.1	7.3	174
16	Herkimer	Sphagnum	—	———	3.9	0.3	6.4	5
17	St. Lawrence	Sphagnum	—	———	4.1	0.8	6.1	7
18	Onondaga	Sphagnum, reed, sedge	6	Non-calcareous sand	3.6	0.8	6.9	15

TABLE 2.—*Reaction of soil, and reaction and calcium content of drainage water at station 8 during the growing season.*

	April 23	May 7	June 4	June 18	June 25	July 2	July 9	July 23	Aug. 8	Sept. 3	Sept. 17
Surface soil (8 inches), pH	5.5	5.1	5.2	5.4	5.2	5.2	5.3	5.4	5.4	5.4	5.5
Drainage water, pH	7.5	7.2	7.2	7.3	7.2	7.0	7.0	7.0	7.3	7.2	7.2
Drainage water, Ca*	47	72	59	20	61	51	49	51	61	31	37

*Calcium, expressed in p.p.m. of solution.

Kurz[3] has shown that the dominance of sphagnum in bogs results in high acidity. He found sphagnum moss to have a reaction of pH 3.8. This figure is in close agreement with the values shown in Table 1 for the samples of sphagnum moss which were collected at stations 16 and 17. The waters collected at these stations were taken at the surface of the bogs and they were not found to be very acid.

Thompson, Lorah, and Rigg[4] report the sphagnum bog waters of the Puget Sound region to be acid in reaction. From a series of experiments, they concluded that the acidity of these waters, which were found to vary in reaction from pH 3.83 to pH 4.95, was controlled primarily by the amount of organic matter present in the waters. The relatively low acidity of the waters from the sphagnum bogs at stations 16 and 17 may have been due to the infiltration of alkaline drainage from the surrounding upland soil.

In Table 1, calcium is shown to be comparatively low in the waters associated with sphagnum. The depth of the peat deposit and the material with which it is underlain appear to influence the amount of calcium in the drainage water. The element was found to be highest in the waters which were collected from deposits not more than 4 feet in depth and which rest on calcareous material.

SEASONAL CHANGES IN REACTION AND CALCIUM CONTENT

Analyses were made of the water at station 8 for reaction and calcium content at intervals during the growing season. The hydrogen-ion concentration of the soil was determined during the same period. Table 2 shows the soil of that station to be a woody-reed peat, to be underlain with calcareous sand at a depth of approximately 10 feet, and to contain 4.4% of calcium oxide. Determinations were made at intervals from April 23 to September 17.

Both the reaction and the calcium content of the drainage were remarkably constant during the course of the test as also was the reaction of the soil from which the drainage came. These values are recorded in Table 2. During the season the soil remained acid while the drainage water was either neutral or slightly alkaline.

DISCUSSION AND CONCLUSIONS

The drainage waters from the cultivated peat soils of the investigation were found in general to be slightly alkaline in reaction and to

[3]Kurz, Herman. Influence of sphagnum and other mosses on bog reactions. Ecology, 9:56–69. 1928.

[4]Thompson, T. G., Lorah, J. R., and Rigg, G. B. The acidity of the waters of some Puget Sound bogs. Jour. Amer. Chem. Soc., 49:2981–2988. 1927.

contain calcium in varying concentrations. Some of the waters from peats of relatively high acidity are acid in reaction. The drainage water from the cultivated types of peat was found to be acid in reaction when the material underlying the deposit is non-calcareous. Whether a deposit rests on calcareous or non-calcareous material appears to determine, to some degree at least, the relative acidity of the upper layers of the deposit and the reaction of the drainage water from the upper few feet of soil. Waters associated with sphagnum moss were found to be acid in reaction.

There is little doubt that the reaction of the ground water is influenced by the character of the material below the peat bed. The reaction of this water, as it moves upward through the peat, seems to bear an important relationship to the reaction of the drainage water from the upper zone of the deposit. But the condition that causes the drainage water to be alkaline has not resulted in neutralizing the acidity of the corresponding soil nor has it brought about an appreciable accumulation of carbonate in the soil as is shown from analyses that are published elsewhere.[5]

In addition to its apparent effect on the hydrogen-ion concentration of the drainage water, the ground water, according to its nature, appears to determine to a considerable degree the concentration of calcium in the drainage waters. If the peat deposits are relatively shallow and underlain with calcareous material the drainage water from the soils is likely to contain comparatively large quantities of calcium.

The reaction of the drainage waters from the principal types of peat soil under cultivation in New York is characteristically alkaline and the reaction of the soils is characteristically acid. These values appear to change but little during the growing season. When the drainage waters were found to be acid they were associated with exceedingly acid soils which are underlain with non-calcareous material.

[5]WILSON, B. D., and STAKER, E. V. The chemical composition of the muck soils of New York. Cornell University Agr. Exp. Sta. Bul. 537.

PRODUCTION AND UTILIZATION OF SOYBEANS AND SOYBEAN PRODUCTS IN THE UNITED STATES[1]

W. L. BURLISON and O. L. WHALIN[2]

The soybean interests have been passing through a steady development in the United States during the last 20 years, but it was not until about 15 years ago that producers and industrialists began to realize the far-reaching possibilities of this crop. Production records were somewhat scattered and fragmentary for the period 1917 to 1924. From that time to the present date, records seem to be reasonably

TABLE 1.—*Production of soybeans harvested for beans, selected states and the United States, 1924–31, 1,000 bushels.**

State	1924	1925	1926	1927	1928	1929	1930	1931
Ohio	195	165	247	350	555	710	688	1,098
Ind.	653	400	529	884	1,000	1,420	1,834	2,837
Ill.	1,380	1,431	1,750	2,392	3,069	3,960	5,504	6,138
Mich	19	20	22	16	30	18	20	36
Wis.	72	18	11	10	25	11	12	10
Iowa	120	140	300	276	357	560	816	961
Mo	656	672	830	1,092	1,288	1,610	1,444	2,184
Kan	46	77	80	72	82	95	174	285
Del.	110	105	140	224	270	168	107	276
Md.	69	75	50	36	44	43	30	75
Va.	180	143	195	196	182	117	98	210
W. Va	42	38	52	48	29	30	19	30
N. Car	1,160	1,348	1,378	1,410	1,380	1,944	1,752	2,838
S. Car.	60	90	80	80	50	80	128	136
Ga.	126	60	84	42	30	64	105	117
Ky.	40	42	32	24	23	25	21	40
Tenn.	80	60	100	72	145	176	240	270
Ala.	28	35	20	16	18	11	14	30
Miss	56	90	63	78	120	140	70	145
Ark.	30	30	25	24	17	54	28	54
La.	40	60	51	72	53	104	120	105
Okla	28	32	24	45	52	94	99	126
U. S.	5,190	5,131	6,063	7,459	8,819	11,434	13,323	18,001

*References: 1924–26, mimeographed report on soybeans and cowpeas, Bureau of Agricultural Economics, February, 1929; 1927 and 1928, Crops and Markets, December, 1928; 1929 and 1930, Agricultural Yearbooks, 1930 and 1931; 1931, crop report of November 11, 1931. All U. S. Dept. of Agriculture. Since preparing this report, production figures for 1929, 1930, and 1931 have been revised, Crops and Markets, U. S. Dept. of Agriculture, December, 1931.

[1]Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Also presented at the annual meeting of the Society held in Chicago, Ill., November 19, 1931. Received for publication December 11, 1931.

[2]Head of Deparment and formerly Research Assistant in Agricultural Economics, respectively.

trustworthy. In 1924, 22 states produced the bulk of soybeans. The total harvested production for the United States in 1924 was slightly above 5,000,000 bushels. During the period 1924 to 1931, production trebled. The figures for 1931 indicate a total return of more than 18,000,000 bushels.

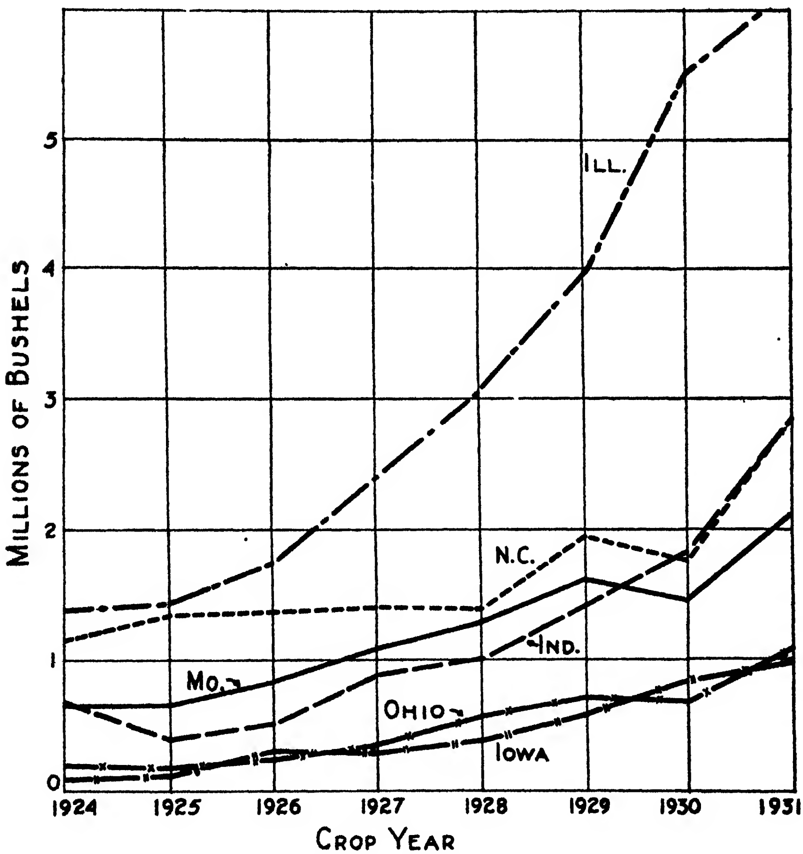

Fig. 1.—Production of soybeans harvested for beans in the six leading producing states, 1924-31.

In 1924, Illinois ranked first in soybean production with North Carolina second, Missouri third, and Delaware fourth. The 1930 rating was Illinois first, Indiana second, North Carolina third, and Missouri fourth.

Table 1 shows the production by leading states, year by year, from 1924 to 1931, while Fig. 1 represents actual production harvested for beans in the six leading states for the same period. These increases are nothing less than remarkable.

ACREAGE

Up to 1925, the acreage of soybeans in the United States fluctuated rather noticeably, but from that period to 1931 this fluctuation has been less marked. The acreages from 1925 to 1931 have shown steady, regular trends upward. Since 1922 the acreage of soybeans has more than trebled in the United States, reaching a total[3] of 3,758,000 in 1930, with an approximate increase of 22% estimated for 1931. The more rapid increase has occurred in the corn-belt states, particularly Illinois, Missouri, and Indiana.

TABLE 2.—*Total equivalent solid acreage of soybeans, selected states and the United States, 1922-30, 1,000 acres.**

State	1922	1923	1924	1925	1926	1927	1928	1929	1930
Ohio	90	128	89	69	105	142	166	180	179
Ind	113	172	217	157	195	218	294	331	402
Ill	169	272	358	330	388	465	497	544	719
Mich	12	14	11	12	12	10	12	10	8
Wis	48	48	25	16	12	11	18	11	10
Iowa	22	29	60	53	56	75	65	86	103
Mo	53	149	208	192	296	369	407	436	463
Kan	—		10	12	12	9	13	18	30
Del	6	14	17	14	17	24	25	27	28
Md	18	24	39	38	43	42	41	38	41
Va	63	73	107	116	122	128	121	115	117
W. Va	7	1	37	33	54	40	32	31	19
N. Car	225	260	215	246	295	304	326	370	478
S. Car	10	21	29	60	67	60	44	45	76
Ga	12	32	71	90	72	83	59	76	106
Ky	65	65	50	57	60	48	85	94	86
Tenn	154	157	200	170	261	335	305	329	339
Ala	113	106	112	134	105	113	58	69	82
Miss	43	45	80	103	110	186	123	140	134
Ark.	—	—	28	37	43	65	64	90	83
La	3	8	30	36	37	50	62	134	158
Okla	—	—	10	12	13	25	35	61	84
N. Y				—	—		3	3	3
N. J	—	—	—		—	—	1	1	1
Penn	—	—	—	—	-	-	9	8	9
U. S	1,226	1,618	2,003	1,987	2,375	2,802	2,865	3,247	3,758

*References: 1924 1928, mimeographed report on soybeans and cowpeas, Bureau of Agricultural Economics, February, 1929; 1922, 1923, 1929, and 1930, Agricultural Yearbooks for crops indicated; 1930, unpublished data from Crop Reporting Service and subject to revision. All U. S. Dept. of Agriculture.

[3]Total acreage refers to the total equivalent solid acreage. This is arrived at by adding to the acreage cut for hay and harvested for beans that harvested by livestock, which is grown mainly with other crops and is divided by some factor, 10 in Illinois, to reduce it to an equivalent solid acreage. Potential production represents the product of acreage and estimated yield of matured beans.

It is rather clear from Table 2 and Fig. 2 that soybeans are becoming a crop of major significance.

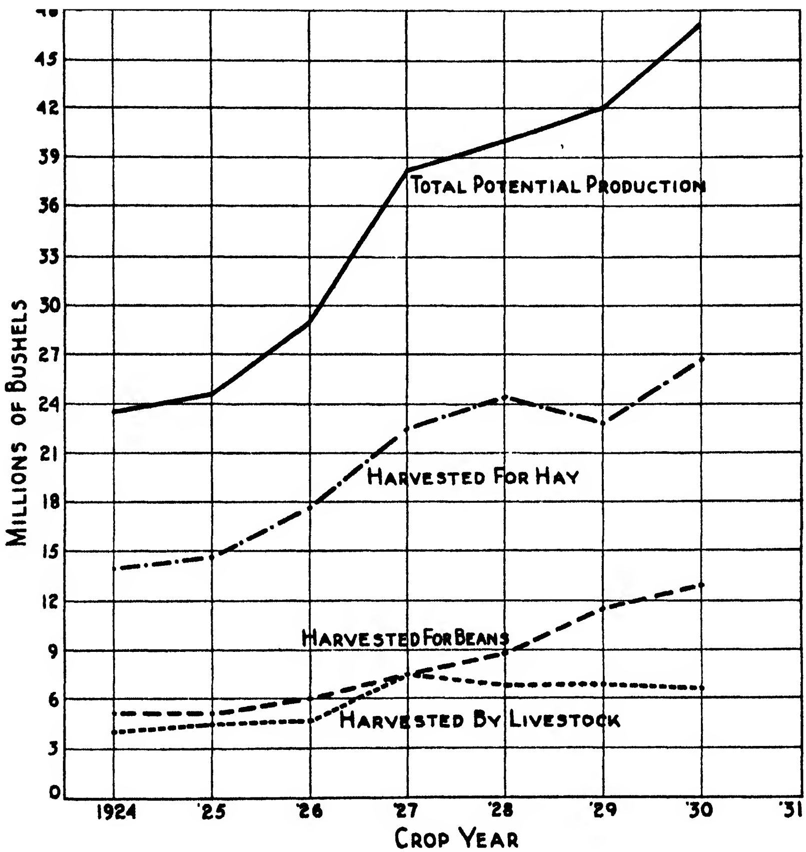

FIG. 2—Potential production of soybeans from total equivalent solid acreage, hay acreage, and acreage harvested by livestock, and actual production from acreage harvested for beans, United States, 1924–30

YIELD PER ACRE

The yield per acre of soybeans has fluctuated considerably from season to season, but possibly less than certain other standard crops. There is some evidence to indicate that the fluctuation in yield of soybeans is somewhat less than formerly, due to superior varieties and to improved cultural practices.

Yield trends in Illinois and Indiana have been distinctly upward, while in North Carolina, Virginia, and Maryland the reverse has been true (Table 3).

TABLE 3.—*Yield in bushels per acre of soybeans, selected states and the United States, 1922–30.**

State	1922	1923	1924	1925	1926	1927	1928	1929	1930
Ohio	15.0	16.0	13.0	15.0	13.0	16.0	15.0	14.5	13.5
Ind	12.0	14.0	9.9	10.0	12.6	13.0	14.5	14.2	14.0
Ill	12.5	14.0	12.0	13.5	12.5	13.0	16.5	16.5	16.0
Mich	10.2	11.0	12.7	13.0	14.4	8.0	15.0	9.0	10.0
Wis	11.0	8.0	9.0	9.0	11.0	10.0	12.5	11.0	11.5
Iowa	22.0	17.0	12.0	12.0	15.0	12.0	12.0	12.0	10.0
Mo	11.0	12.0	9.5	10.5	10.0	10.5	12.5	10.0	9.5
Kan	—	—	11.5	9.6	10.0	12.0	10.2	9.5	8.7
Del	14.3	15.4	11.0	15.0	14.0	16.0	18.0	10.5	6.3
Md	16.0	17.5	14.0	15.0	15.0	16.0	14.8	14.4	7.5
Va	16.0	19.0	13.0	13.0	14.0	14.0	13.0	9.0	7.5
W. Va	15.0	15.0	16.0	13.5	13.0	15.0	14.5	15.2	9.6
N. Car	16.0	17.0	13.5	13.5	12.0	17.0	15.0	14.0	13.0
S. Car	11.0	12.0	11.0	10.0	10.0	11.5	14.0	13.5	10.5
Ga	12.2	11.0	9.5	6.5	11.0	11.0	12.0	10.0	10.0
Ky	13.0	14.0	12.5	13.0	14.0	14.0	14.0	15.0	11.5
Tenn	9.0	9.0	12.5	12.0	13.5	13.0	11.0	10.0	13.0
Ala	8.6	9.0	13.5	14.0	9.5	13.0	14.0	14.0	12.0
Miss	12.0	14.5	12.5	17.5	13.0	14.0	15.5	13.5	10.5
Ark	—	—	13.5	11.0	11.0	15.0	15.0	14.0	10.5
La	12.1	16.0	11.0	14.0	12.0	12.5	12.0	9.3	10.5
[illegible]	—	—	10.0	9.0	9.0	11.0	10.8	8.0	8.0
U. S.	13.8	14.5	11.8	12.4	12.2	13.6	14.2	13.0	12.6

*References: 1924 to 1926, mimeographed report on soybeans and cowpeas, other years, Agricultural Yearbooks, 1923, 1928, 1930, and 1931. All U. S. Dept. of Agriculture. Since preparing this report, yield figures for 1929 and 1930 have been revised, Crops and Markets, U. S. Department of Agriculture, December, 1931.

ACREAGE HARVESTED FOR BEANS

There has been a steady increase in soybean acreage harvested for beans since 1925, but the most rapid development has occurred since 1928. The latter period marks the rapid expansion of the use of soybeans in the industries. It will be observed from Table 4 that the acreage of soybeans harvested for beans has more than doubled since 1928.

ACREAGE HARVESTED FOR HAY

Soybean acreage cut for hay has increased steadily since 1925 with the greatest expansion in the more recently developing area of the corn-belt states. Expansion of hay acreage apparently precedes that of marked development of bean production in most areas and reaches an approximate maximum earlier. The acreage increased from 1,181,000 in 1925 to 2,100,000 in 1930, with the largest hay sections located in Illinois, Missouri, Tennessee, and Indiana, as indicated in Table 5.

TABLE 4.—*Acreage of soybeans harvested for beans, selected states and the United States, 1922–31, 1,000 acres.**

State	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931
Ohio	31	50	15	11	19	35	37	49	51	61
Ind.	20	46	66	40	42	68	69	100	131	164
Ill	65	92	115	106	140	184	186	240	344	372
Mich.	4	6	2	2	2	2	2	2	2	3
Wis	7	4	8	2	1	1	2	1	1	1
Iowa	6	7	10	10	20	23	21	35	52	62
Mo.	15	70	69	64	83	104	103	161	152	182
Kans.	—	—	4	8	8	6	8	10	20	30
Del.	2	10	10	7	10	14	15	16	17	19
Md.	5	7	6	6	4	3	3	3	4	5
Va	13	15	15	13	15	14	14	13	13	14
W. Va	1	1	3	3	4	3	2	2	2	2
N. Car.	100	125	80	93	106	94	120	162	219	258
S. Car	3	5	12	20	20	16	9	8	16	20
Ga	3	7	18	12	14	7	5	8	14	18
Ky	6	6	5	6	4	3	3	3	3	4
Tenn	6	7	10	8	12	9	23	27	30	36
Ala	18	25	4	5	4	3	3	2	3	5
Miss	8	8	8	9	9	12	12	14	14	22
Ark	—	—	5	6	5	6	2	8	7	9
La	1	1	5	6	6	8	10	12	15	15
Okla	—	—	4	4	4	6	7	17	18	18
U. S.	314	492	474	441	532	621	656	893	1,128	1,320

*References: 1922, 1923, 1929, and 1930, Agricultural Yearbooks, years 1923, 1924, 1930, and 1931; 1924-1928, mimeographed report, Bureau of Agricultural Economics, February, 1929; 1931, crop report of November 11, 1931, Bureau of Agricultural Economics. All U. S. Dept. of Agriculture. Since preparing this report, acreage figures for 1929, 1930, and 1931 have been revised, Crops and Markets, U. S. Dept. of Agriculture, December, 1931.

ACREAGE HARVESTED WITH LIVESTOCK

The practice of seeding soybeans with other crops is largely confined to the southern states, notably at present, North Carolina, Tennessee, Louisiana, Mississippi, South Carolinà, and Arkansas. States in the corn belt have not increased their acreage of beans seeded with corn in ratio to the increased production for hay and beans. In the more important hog producing sections, however, there is a considerable area devoted to soybeans in corn.

It will be observed from Table 6 that the acreage of soybeans grown with other crops and harvested with livestock has not increased during the last 4 years.

IMPORTS OF CERTAIN SOYBEAN PRODUCTS

The amount of soybeans imported into the United States has been surprisingly constant from year to year. At no time during the last

10 years have the imports amounted to as much as 4½ million pounds. The importation of beans for 1930 was only 65,000 bushels, not a very significant quantity. (See Table 7, column 3, and Fig. 3.)

TABLE 5.—*Acreage of soybeans harvested for hay, selected states and the United States, 1922–30, 1,000 acres.**

State	1922	1923	1924	1925	1926	1927	1928	1929†	1930†
Ohio	30	50	39	30	45	67	108	110	118
Ind	29	40	109	93	111	118	161	164	230
Ill	70	137	200	184	210	245	277	274	345
Mich	4	4	7	8	9	7	10	8	6
Wis	11	14	13	11	10	10	15	9	9
Iowa	7	7	20	15	10	26	36	42	42
Mo	33	68	131	121	204	255	293	262	296
Kans	—	—	5	3	4	3	5	8	10
Del	3	3	7	7	7	10	10	11	11
Md	10	12	32	31	36	36	36	34	36
Va	40	48	85	96	100	105	100	95	97
W. Va	5		31	28	49	37	29	28	17
N. Car	65	70	80	91	121	120	108	120	156
S. Car	4	9	11	22	22	18	15	18	25
Ga	7	20	37	35	54	58	48	65	91
Ky	38	38	39	48	45	38	49	80	72
Tenn	125	130	169	144	212	197	191	219	230
Ala	60	52	80	100	80	90	50	60	66
Miss	19	23	46	63	65	113	79	84	80
Ark	—	—	15	22	32	47	30	44	40
La	1	6	20	22	23	26	26	35	55
Okla	—	—	5	7	6	14	21	35	55
N. Y	—	—	—		—	—	3	3	3
N. J	—	—	—	—	—	—	1	1	1
Penn	—	—	—	—	—	—	9	8	9
U. S	561	731	1,181	1,181	1,455	1,653	1,710	1,817	2,100

*References: 1922, 1923, and 1929, Agricultural Yearbooks, years 1923, 1924, and 1930; 1924–1928, mimeographed report, Bureau of Agricultural Economics, February, 1929; 1930, Agricultural Yearbook 1931 and unpublished data from Crop Reporting Service. All U. S. Dept. of Agriculture.

†1929 and 1930 represent differences between total equivalent solid acreage and the total acreage except for hay.

For a considerable period imports of soybean meal and cake were very irregular. Upward trends seemed apparent from about 1925 to 1930 when tariff duties became effective on soybean meal and cake for the first time. In 1930, imports amounted to less than 6,000 tons. The first half of 1931 showed an increase over 1930.

Imports of soybean oil have likewise been affected by the tariff. During the war period soybean oil imports reached significant proportions, amounting to 335,984,000 pounds in 1918. Since that time imports have declined irregularly but continually. The first marked

drop occurred in 1921 when the emergency tariff measure of that year took effect. Since then yearly variations have not been very marked except as influenced by variation in production.

As the 1930 tariff duties became effective further reduction in imports became apparent.

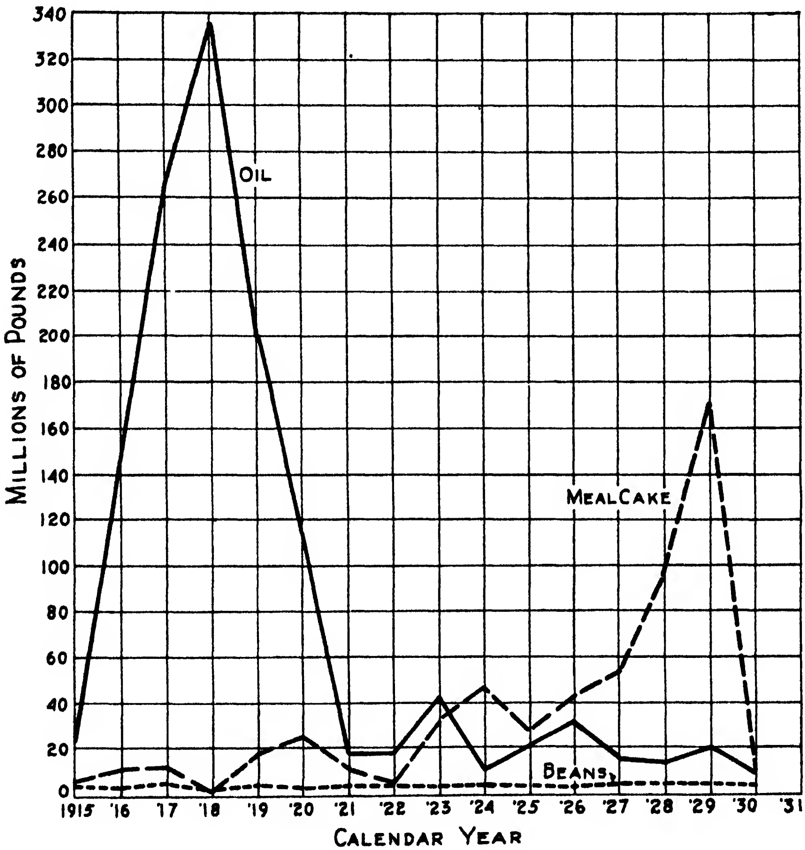

FIG. 3.—Imports of soybeans, soybean oil, and soybean cake and meal into the United States, calendar year, 1915–30.

PRODUCTION OF IMPORTANT OILS IN THE UNITED STATES

Total oil production does not fluctuate greatly from year to year. Production increased gradually for the period following the close of the World War until 1927. Since then the trend has been downward. The annual total production exclusive of butter fat was slightly above 5¼ billion pounds in 1930, approximately three-fifths of which represented animal fats and fish oils and two-fifths vegetable oils. Cotton-

seed oil production has been by far the most important of the vegetable oils, being about 1½ billion pounds, followed by linseed oil and corn oil. Soybean oil has been of minor importance in actual totals but has increased rapidly since 1928. The production was more than 14 million pounds in 1930 and has more than doubled during 1931. The production of the other important oils has been fairly stable over the period of the last 5 years, as shown in Table 8.

TABLE 6.—*Acreage of soybeans harvested with livestock,* selected states and the United States, 1922–30, 1,000 acres.†*

State	1922	1923	1924	1925	1926	1927	1928	1929	1930
Ohio	29	28	35	28	41	40	21	21	10
Ind.	64	86	42	24	42	32	56	67	41
Ill	34	43	43	40	38	36	34	30	30
Mich.	4	4	2	2	1	1	—	—	—
Wis.	30	30	4	3	1	—	1	—	—
Iowa	10	15	30	28	26	26	9	9	9
Mo.	5	11	88	7	9	10	12	13	15
Kans.	—	—	1	1	—	—	—	—	—
Del.	1	1	—	—	—	—	—	—	—
Md.	3	5	1	1	3	3	2	1	1
Va.	10	10	7	7	7	9	7	7	7
W. Va	1	—	3	2	1	—	1	—	—
N. Car	60	65	55	64	68	90	98	88	103
S. Car	3	7	6	18	25	26	20	19	35
Ga	2	5	16	43	4	18	6	3	1
Ky.	21	21	6	3	11	7	12	11	11
Tenn	23	20	21	18	37	129	107	83	79
Ala.	35	29	28	29	21	20	5	7	13
Miss.	16	14	26	31	36	61	32	42	40
Ark	—	—	8	9	6	12	32	38	36
La	1	1	5	8	8	16	26	87	88
Okla	—	—	1	1	3	7	7	9	11
U. S.	352	395	348	367	388	543	488	535	530

*Not published separately, 1925–27 represent the differences between the total equivalent solid acreage and the sum of the acreages harvested for beans and for hay. 1928, 1929, and 1930 represent the differences between total except for hay and that from which beans were gathered.

†References: 1922, 1923, 1929, and 1930, Agricultural Yearbooks, 1923, 1924, 1930, and 1931. 1924-1928, mimeographed report, Bureau of Agricultural Economics, February, 1929. All U. S. Dept. of Agriculture.

NET IMPORTS OF OILS AND FATS INTO THE UNITED STATES

Since 1917 there has been a gradual increase in net imports or imports for consumption[4] of oils and fats into the United States, due largely to the increased imports of cocoanut oil and copra. Cocoanut oil and copra represented in 1930 slightly more than one-third of

[4]Net imports represent imports less re-exports of the given oils and fats.

the total net imports. It will be observed from Table 9 that net imports of total oil and fats amounted to 1,810,226,000 pounds; cocoanut oil and copra, 679,821,000 pounds; palm oil, including palm kernel, 315,618,000 pounds; and linseed oil and flax seed, 236,118,000 pounds. In 1930, net imports of soybean oil dropped to 3,386,090 pounds.

TABLE 7.—*Imports into United States of soybean oil, soybean meal and cake, and soybeans, 1915–31.**

Year	Soybean oil, pounds	Soybean meal and cake, pounds	Soybeans, pounds
1915	21,335,000	5,976,000	3,837,865
1916	145,409,000	10,468,000	3,004,000
1917	264,926,000	11,761,000	5,344,000
1918	335,984,000	78,000	1,433,000
1919	195,808,000	16,989,000	4,368,780
1920	112,214,000	24,473,000	3,136,850
1921	17,283,000	10,637,000	3,946,173
1922	17,294,000	4,282,000	3,536,807
1923	41,679,000	31,224,000	3,648,243
1924	9,125,000	47,085,000	4,184,120
1925	19,493,000	27,802,000	3,811,897
1926	30,712,000	42,869,000	3,727,628
1927	14,915,000	53,951,000	4,189,168
1928	13,116,000	96,810,000	4,255,734
1929	19,489,000	171,855,000	4,337,160
1930	8,348,000	11,626,000	3,851,796
1931†	2,175,000	24,749,000	1,945,789

*Reference: Monthly summaries of foreign commerce, U. S. Dept. of Commerce.
†Six months only

Total net imports of all oils and fats have been slightly more than one-third of production. Exports of vegetable oils, including re-exports have been small since readjustments following the World War. In 1930, exports of leading vegetable oils represented less than one-twentieth of the net imports of all vegetable oils (Table 10). The proportion of soybean oil exported relative to that imported was important, however, reaching one-third of imports. During the first nine months of 1931 soybean oil exports were nearly equal to imports.

IMPORT DUTIES LEVIED ON SOYBEANS AND SOYBEAN PRODUCTS

The emergency tariff of 1921 was the first tariff to place a duty on a soybean product. A duty of 20 cents per gallon (2.67 cents per lb.) was placed on the oil, which immediately shut out the greater portion of soybean oil imports, as has been indicated earlier. The tariff of the following year decreased the duty on soybean oil to 2.5 cents per

TABLE 8.—*Domestic production of soybean oil and other oils and fats from domestic materials, 1916–30, 1,000 pounds.**

Calendar year	Cottonseed oil†	Peanut oil†	Olive oil	Corn oil†	Linseed oil‡	Soybean oil	Total vegetable oil	Animal fats and fish oils§	Grand total
1916	1,492,430	28,534	1,462	109,963	251,746	—	1,884,135	2,628,125	4,512,260
1917	1,343,849	50,499	963	118,021	154,921	—	1,668,253	2,252,161	3,820,414
1918	1,283,823	95,934	618	111,065	238,487	—	1,729,927	2,755,886	4,485,813
1919	1,429,948	87,607	439	97,400	119,971	—	1,735,365	2,822,314	4,457,679
1920	1,142,671	13,085	643	98,619	193,322	—	1,448,340	2,868,285	4,316,625
1921	1,277,300	33,234	974	87,481	141,421	—	1,540,410	3,009,888	4,551,298
1922	934,627	22,644	585	111,508	176,477	751	1,246,592	3,371,085	4,617,677
1923	973,753	5,359	574	111,343	297,401	1,404	1,389,834	3,969,423	5,359,257
1924	1,154,434	6,691	1,509	117,065	549,648	950	1,830,297	3,833,056	5,663,353
1925	1,510,802	15,156	532	104,153	411,908	2,520	2,045,071	3,247,580	5,292,651
1926	1,764,318	10,644	1,383	120,041	354,743	2,646	2,253,775	3,413,032	5,666,807
1927	1,806,757	10,590	858	117,441	448,728	3,088	2,427,462	3,412,970	5,840,432
1928	1,460,407	12,439	1,438	124,327	366,304	4,716	1,969,631	3,589,244	5,558,875
1929	1,581,631	16,131	1,003	133,680	312,858	11,009	2,056,312	3,343,510	5,399,822
1930	1,616,102	25,495	2,184	120,747	393,307	14,387	2,172,222	3,052,894	5,225,116

*References: Certain Vegetable Oils, part 2, pages 93–96, U. S Tariff Commission; and Foreign Crops and Markets, annual issues on vegetable oils and oil seeds, 1926–1931, U. S. Dept. of Agri ulture.

†Crude oil only.

‡Oil equivalent of domestic seed production less exports.

§Excludes butterfat which averages about 1,800,000,000 pounds annually.

TABLE 9.—*Net imports of animal and vegetable oils and fats, with special reference to soybean oil and five other kinds of vegetable oils, oil equivalent being used for imported materials, United States, 1916–30, 1,000 pounds.**

Calendar year	Soybean oil	Cocoanut oil and copra	Peanut oil	Olive oil (edible)	Olive, inedible including olive oil foots	Palm oil, including palm kernel	Linseed oil and flaxseed	All other vegetable oils and materials	Total vegetable oils and materials	Animal and fish oils and greases	Grand total
1916	143.347	159,081	15,503	55,043	20,508	29,214	245,206	94,463	762,365	44,879	807,244
1917	260,949	378,906	27,259	50,619	12,778	30,227	175,978	60,005	996,721	59.423	1,056,144
1918	335,439	613,266	68,392	1,128	161	20.993	242,383	95,281	1,377,043	67,739	1,444,782
1919	178,075	297,378	153,960	67,195	8,659	41,563	278,098	53,428	1,078,356	72,958	1,151,314
1920	108,985	316,132	95,095	30,144	9,124	41,812	495,169	48,464	1,144,925	90,375	1,235,300
1921	16,771	291,571	2,592	49,514	20,139	22,770	290,179	31,850	725,386	62,644	768,030
1922	16,875	372,249	2,429	61,120	26,937	56,796	422,515	93,700	1,052,621	69,929	1,122,550
1923	41,507	375,615	7,925	77,120	40,605	126,800	497,299	129,181	1,296,052	93,553	1,389,605
1924	8,848	371,846	5,194	76,074	31,918	100.133	322,906	228,306	1,145,225	89,966	1,235,191
1925	18,973	444,418	2,687	90,084	50,050	188,217	353,207	146,387	1,294,023	93,448	1,387,471
1926	29,145	526,616	26,660	80,777	50,703	205,727	479,710	108,059	1,507,397	141,383	1,648,780
1927	9,471	556,097	19,394	75,025	49,126	199,180	404,198	145,040	1,457,531	148,400	1,605,931
1928	5,974	592,277	31,295	82,944	48,271	219,652	324,032	170,757	1,475,202	164,658	1,639,860
1929	11,522	753,689	14,489	96,798	56,206	329,072	457,971	303,581	2,023,328	187,738	2,202,066
1930	3,386	679,821	17,052	92,964	69,896	315,618	236,118	245,597	1,660,452	149,774	1,810,226

*References: Certain Vegetable Oils, part 2, page 97, U. S. Tariff Commission; and Foreign Crops and Markets, annual issues on vegetable oils and oil seeds, 1926–1931, U. S. Dept. of Agriculture.

pound (18.75 cents per gallon) and levied a duty of 0.5 cent per pound (30 cents per bushel) on soybeans.

TABLE 10.—*Exports of soybean oil and other leading vegetable oils, United States, 1919–31, 1,000 pounds.**

Year	Soybeans	Cotton-seed	Cocoa-nut	Linseed	Corn	Peanut
1919	27,715†	193,133	118,612	11,266	6,452	4,342
1920	43,512	184,754	25,695	5,366	12,059	1,425
1921	1,944	252,549	7,498	3,512	4,400	1,708
1922	2,458	75,303	12,972	2,703	5,733	963
1923	1,356	49,608	16,562	3,013	4,361	203
1924	2,264	43,343	17,961	2,387	3,679	39
1925	520	62,415	17,901	2,487	3,847	—
1926	1,567	40,901	15,952	2,567	1,324	—
1927	6,629	67,982	26,275	2,525	310	898
1928	9,094	51,702	31,184	1,965	337	42
1929	8,096	26,075	30,871	2,208	315	103
1930	5,479	29,193	26,904	1,592	613	7,702
1931‡	5,787	19,593	13,960	917	662	7,189

*References: Wright, P. G., The tariff on animal and vegetable oils, pages 264–265, 1928. Zimmerman, Harvey J. Animal and vegetable fats and oils, 1927 to 1930, U. S. Dept. of Commerce. 1931.
†Second 6 months only.
‡First 9 months only.

TABLE 11.—*Duties levied on soybean oil, soybean cake and meal, and soybeans by the tariffs of 1909, 1913, 1921, 1922, and 1930.**

Year of tariff	Oil	Cake and meal	Beans
1909	Free list	Free list	Free list
1913	Free list	Free list	Free list
1921	20c per gal. (2.67c per lb.)	Free list	Free list
1922	2.5c per lb. (18.75c per gal.)	Free list	½c per lb. (30c per bu.)
1930	3.5c per lb. (26.25c per gal.)	$6 00 per ton	$1.20 per bu.

*References: Comparison of tariff acts, 1922, 1913, and 1909; tariff act of 1930, House Document 476, 71st Congress, 2nd Session, 1930.

TABLE 12.—*How the 1929 and 1930 crops of soybeans were utilized in the United States.**

1929 Crop

Total equivalent solid acreage, 3,245,000	Hay, 56% Grazed, 16% Beans, 28% 11,434,000 bu.	Seed, 12% Crushed or ground, 7% Feed, 9%

1930 crop

Total equivalent solid acreage, 3,758,000	Hay, 56% Grazed, 14% Beans, 30% 13,323,000 bu.	Seed, 10.5% Crushed or ground, 11.5% Feed, 8%

*Expressed in terms of percentage of total equivalent solid acreage.

These duties apparently made little change in importations. The recent tariff of 1930 increased the duty on oil to 3.5 cents per pound and on beans to $1.20 per bushel. Soybean cake and meal was taken from the free list and given a duty of $6.00 per ton (Table 11). Since then importation of all soybean products has decreased.

TABLE 13.—*Utilization of soybeans and soybean products in the United States, 1930 crop.**

1. Beans, 13,323,000 bus.	Feed, 3,500,000			
	Seed, 4,623,000			
	Ground, 400,000	Food, 200,000		
		Feed, 200,000		
	Crushed, 4,800,000			
2. Oil, 37,200,000 pounds	Edible	Lard substitutes,		500,000
		Oleomargine,		750,000
		Other food products,		4,750,000
	Paint and other industrial uses	Paint and varnish,		9,000,000
		Linoleum and oil cloth,		4,000,000
		Other,		3,500,000
	Soap kettle,			8,500,000
	Increased stocks including oil equivalent,			5,700,000
3. Meal, 110,000 tons	Feed	Commercial feeds,		89,100
		Other,		20,000
	Food	Flour		850
		Infant and diabetic foods,		50
	Competition	Cotton seed meal,		2,350,000
		Linseed oil meal,		1,750,000
		Soybean meal,		110,000
			Total	4,210,000

*Imports of soybean oil and beans about balanced exports of soybean oil for the year Oct. 1, 1930, to Sept. 30, 1931.

UTILIZATION OF SOYBEANS IN UNITED STATES

The soybean crop for 1929 amounted to 3,245,000 total equivalent solid acreage. This crop was utilized as follows: for hay, 56%; grazed, 16%; harvested as beans, 28%. In 1930, the hay acreage remained proportionately the same as for 1929, while the area grazed fell 2%, but the acreage harvested for beans increased 2%. An interesting point observed in Table 12 is that more than half of the soybean acreage is utilized for hay.

Table 13 expresses in a different way facts pointed out in Table 12 with reference to the 1930 crop. It may be noted that of 13,323,000 bushels of beans harvested the amounts used for seed and crushed were about the same. It is worth while to note that of the 37,200,000 pounds of oil produced in the United States, one-fourth was utilized

in paint and varnishes, about one-eighth in linoleum and oil cloth, nearly one-fourth for soap, and a little over one-fifth for edible purposes.

TABLE 14.—*List of soybean products produced in the United States.*

Food Products, Direct and Indirect	
Soybean flour	Soya cream biscuits
Soybean meal flour	La Choy—soy sauce
Refined edible soybean oil	Soyolk (flour)
Soybean salad oil	Soy biscuits
Chocolate bars (30% soybean flour)	Soy flour
Cocoa (up to 60% soybean flour)	Vi-Zoy
Sausages (up to 50% soybean flour)	Lektizoy
Bread (7½% soybean flour)	Zoy soup
Rolls (10% soybean flour)	Zoybeans (cooked beans)
Macaroni (20% soybean flour)	Bacon and zoy beans
Soybean muffins	Zoy bouillon
Soybean cookies	Soy bean biscuit
Soybean doughnuts	Casein gluten flour
Vegetable shortening	No-fat mayonnaise
Infant foods	Fatless spread
Diabetic foods	Fluffo
Oleomargarine	
Lard substitutes	Canadian Products:
Filled sweets	Milqo (soy milk)
Soybean sprouts	Vi-Tone (chocolate)
Soybean cheese	Soya flour
Soybean milk	Soyex-Malt-Cocoa drink
Soybean buns	Soyex
Soybean ice cream	Macaroni
Feed Products	
Cake or meal	Calf chow
Commercial feed	Lay chow
Dairy feed	Rabbit chow
Dairy chow	34% protein chow chow
Hog chow	24% protein chow chow
Poultry chow	Chick startena
Dog chow	Chicken fatena
Chicken chowder	Olelene
Steer fatena	Grainola
Industrial Uses	
Paint	Lauxtex plastic wall coat
Varnish	Lauxein waterproof soybean glue
Enamels	Lauxein emulsifier
Oil cloth	Soap (liquid)
Linoleum	Soap (potash)
Printers ink	Core binders
Glycerine	Rubber substitutes
Celluloid	

In 1930, the United States produced slightly over 4 million tons of oil meal. Of this amount, soybean meal represented slightly over 2.5%. For the quarter ending June 30, 1931, soybean meal production represented approximately 7% of the total oil meal production in this country.

SOYBEAN PRODUCTS

The list of soybean products included in Table 14 does not pretend to be complete. Attention is called to the large number of food products actually being placed on the market in the United States from soybeans at the present time. This list has grown rapidly during the last year.

Meal is being incorporated into a wide variety of commercial feeds with satisfactory results, and consumption will undoubtedly increase greatly on a competitive price basis.

Industrial users are quite active. Their list for utilization of soybean products is not increasing greatly, but the demand in the more important ones has become more apparent, as indicated by the present consumption trends.

SUMMARY

Soybean acreage harvested for beans has expanded rapidly in the United States since 1925, reaching an estimated production of approximately 18,000,000 bushels for 1931. More than half of the acreage grown each year has been cut for hay. The acreage harvested with livestock has not shown any increase since 1927.

Imports of soybeans and of soybean cake and meal have always been of minor importance. Soybean oil imports represented significant quantities at the close of the World War, however, but have since diminished to negligible amounts as import duties have become effective. The imports of such competing oils as cocoanut and linseed have been of greatest importance.

Approximately one-fourth of the soybean oil being utilized in the United States is going into paints and varnishes, another one-fourth is finding its way to the soap kettle, nearly one-fifth is being used in edible products, and about one-eighth is being consumed in linoleum and water-proofing products. The number of commercial products being placed on the market that contain soybeans or soybean products is increasing rapidly. A most encouraging feature of soybean progress has been the research development in utilization of soybeans and soybean products within the last 2 years and the corresponding expansion in demand along commercial lines.

YIELDS OF PINEAPPLES AS INFLENCED BY FERTILIZATION AND CONFORMITY TO THE LAW OF DIMINISHING INCREMENT[1]

O. C. Magistad, C. A. Farden, and C. B. Lambert[2]

The laws of plant growth and the yields of crops as a function of the quantities of fertilizer used were discussed by Liebig (7)[3] and later put into precise mathematical relations by Mitscherlich (8, 9, 10, 11, 12) and Baule (1, 2). Spillman (15), working with examples of the law of diminishing returns in other economic fields, found that crop yields as a function of fertilizer used was an example of this same law.

Interest in yield equations lies first, in their serving as an accurate concise record of the results obtained in the experiment; second, in the fact that indicator crops for greenhouse pot work can be evaluated by a comparison of the constants of their yield curves with those of the yield curves of the economic crop; and third, in the possibility of evaluating chemical tests of plant food availability by comparison with "b" values as calculated by means of yield equations.

In the present paper, yields obtained in field fertilizer experiments have been treated by the Spillman method of analysis as it seems preferable to that of Mitscherlich. Rarely have American investigators treated the results of fertilizer experiments in a mathematical way as indicated by the authors cited above. The few English references available, such as those of Murray (14), Verret and Kutsunai (17), Kutsunai and Caum (6), Kutsunai (5), and Hartung (4), usually occur in publications having a small circulation. All steps in the calculations are given in the present paper so that the processes may be available to English readers generally.

PLAN OF EXPERIMENT

The field experiment was installed by the Kauai Pineapple Company in December, 1927, for the purpose of checking potash deficiencies as indicated in a field experiment in a neighboring field. Sixty percent of the N, 57% of the P_2O_5, and all but 50 pounds of K_2O was thoroughly incorporated with the top 3 inches of soil in the bed. Mulch paper was next laid over the bed and pineapple crowns

[1]Technical Paper No. 28 of the Experiment Station of the Association of Hawaiian Pineapple Canners, University of Hawaii, Honolulu, T. H. Received for publication December 17, 1931.

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[3]Reference by number is to "Literature Cited," p. 621.

planted through the paper. Each plat consisted of 6 beds each 250 feet long or 0.436 acre in area. Each treatment was replicated four times. There were approximately 9,000 plants per acre.

The remaining nitrogen, P_2O_5, and 50 pounds of K_2O per plat in equal installments were applied in May and November, 1928.

Harvesting of the plant crop was carried on during the summer of 1929. All fruits in the plats were counted and weighed when picked. Fertilizer and harvest data for the plant crop are given in Table 1.

TABLE 1.—*Harvest data for the plant crop.*

Plat	Pounds per acre			Total number of fruits	Total weight of fruit, pounds	Average weight of fruit, pounds	Total tons of fruit	Tons of fruit per acre
	N	P_2O_5	K_2O					
A	287½	150	125	3,692	14,131	3.83	7.07	16.21
B	287½	150	200	3,661	15,068	4.12	7.53	17.27
C	287½	150	300	3,731	15,855	4.25	7.93	18.17
D	287½	150	400	3,663	16,211	4.43	8.11	18.58

Immediately after harvesting the plant crop, one application of fertilizer was applied equally to all plats, and 1 year later, 1930, another fruit crop (first ratoon) was harvested. The term "ratoon crop" is in general use in the Hawaiian Islands, and when applied to pineapples is defined as the crop of suckers or ratoons produced at the base of the mother plants.

Table 2 contains the combined results of the plant and ratoon crops, constituting data for the cycle.

TABLE 2.—*Fertilizer and harvest data for cycle crop.*

Plat	Pounds per acre			Total number of fruits	Total weight of fruit, pounds	Average weight of fruit, pounds	Total tons of fruit	Tons of fruit per acre
	N	P_2O_5	K_2O					
A	407½	207½	245	9,207	34,630	3.76	17.32	39.72
B	407½	207½	320	9,672	37,028	3.83	18.51	42.44
C	407½	207½	420	9,981	39,571	3.96	19.79	45.36
D	407½	207½	520	10,153	40,900	4.03	20.45	46.88

ANALYSIS OF YIELD DATA

Mitscherlich (11) has found by a very great number of experiments that the increase in yield due to a first unit of fertilizer is greater than that due to a second unit of fertilizer, that the increase in yield due to the second unit of fertilizer is greater than that due to the third unit, and so on. This behavior of yield led him to derive empirically an equation which corresponded to such a high degree with experimental results that it is now recognized as the expression

of a law of the soil. The equation is $y = A(1-e^{-cx})$, in which $y =$ yield obtained with a definite quantity of plant food x, $A =$ maximum yield obtainable with large quantities of x, and $c =$ a constant. Mitscherlich has postulated that the best way of ascertaining the effect of any one growth factor is to vary this factor and keep the others constant at a relatively high but reasonable level for plant growth. Spillman's method of analysis handles yield data obtained in field experiments conducted as prescribed by Mitscherlich in a way which seems superior to Mitschrelich's treatment. The Mitscherlich and the Spillman yield equations have been proved by Spillman to be mathematically identical. Mitscherlich, Baule, and Spillman all use equations indicating that the yield will increase to a maximum with addition of a previously lacking plant food. Their equations indicate that this maximum value is approached but never quite attained, and that greater additions of plant food cause the yield to approach this maximum value more closely.

Within the last 2 years papers have appeared by Eichler (3) and Mitscherlich (13) showing that additions of some plant foods cause the yield to pass through a maximum and then to decrease rather rapidly. This descending branch of the yield curve, indicating a depressing action caused by great concentration of the growth factor, has not been considered heretofore. In this paper, yield curves are developed according to the method of Spillman with the understanding that, if the quantity of plant food applied is large enough to be depressing in character, the yield equation will no longer hold.

We have found that the "c" value of Mitscherlich calculated for our field experiments is not constant and does not always approximate the values of Mitscherlich. For this reason we wish to calculate this constant from our data in place of using an arbitrary one. Spillman's method does this easily and accurately, giving us certain R values which can be converted into "c" values. These quantities and their significance will be treated later. They are introduced at this time to indicate an added reason for using Spillman's method.

If we wish to obtain a rough measure of yield increase for equal 100-pound units of potash, we must plot the yields obtained against fertilizer applied to obtain a value for 100 pounds of K_2O in the plant crop and 220 pounds K_2O in the cycle crop. The results obtained by this interpolation, together with the actual results of the experiment, furnish us with a series of yield values corresponding to fertilizers which vary by units of 100 pounds. We are now in a position to show how the data confirm the fact that each additional unit of fertilizer results in a smaller increase in the fruit yield (Table 3).

The last column in Table 3 shows how the gain in fruit weight decreases with increasing applications of potash.

TABLE 3.—*Harvesting results showing smaller increase in fruit weight with each additional unit of fertilizer.*

Units of potash	Pounds of potash per acre	Tons of pineapples per acre	Tons of pineapples gained for each additional 100 lbs. of potash
		Plant Crop	
1	100	15.65	—
2	200	17.27	1.62
3	300	18.17	0.90
4	400	18.58	0.41
		Cycle Crop	
0	245	39.20	—
1	320	42.44	3.24
2	420	45.36	2.92
3	520	46.88	1.52

The ratios of decrease in the successive increments are 1 : 0.556 and 1 : 0.456 for the plant crop and 1 : 0.902 and 1 : 0.522 for the cycle crop. This is very poor agreement, but the method of least squares obtains values of these ratios which, when used in the proper equations, calculate yields that agree very satisfactorily with the observed yields.

The Spillman yield equation, which expresses the relationship between yields and fertilizer applications, is as follows:

$Y = M—AR^x$, where

Y = yield of pineapples in tons per acre.

M = theoretical maximum yield approximated by the application of large amounts of fertilizer but insufficient to cause yield decreases because of injurious effects.

A = possible yield increase due to application of large amounts of fertilizer.

R = the ratio between successive increases in yield caused by equal addition of fertilizer.

x = number of units of fertilizer applied.

EVALUATION OF CONSTANTS

In order to evaluate the constants M, A and R in the formula $Y = M — AR^x$, we have turned to the method of least squares, because the constants determined by this method are the best that will fit the actual data. It is not the purpose of this paper to develop the method of least squares, but simply show how to apply the method to observation equations so as to obtain the best values of the constants. The method derives its name from the fact that the most probable values of the constants are obtained when the sum of the

squares of the difference between the observed and computed values is a minimum.

Spillman (15) gives two methods based on the principle of least squares. The first (15 pages 14–17) is applicable only when the units of fertilizers used increase by unity. Logarithms of the yield increase per unit are used in the calculations. In experiments where negative increases take place, this method fails because negative numbers do not have logarithms. Thus, in experiments where the yield does not regularly increase with each additional unit of fertilizer applied, the first method of Spillman is inapplicable.

Spillman's second method is more accurate in evaluating the constants, M, A, and R, but the work involved is great because very often normal equations are obtained which contain high powers of R, thus requiring the use of calculating machines or logarithm tables. Spillman has outlined this method briefly (15, pages 70–75). Anyone familiar with the theory of least squares and the calculus will confirm the following three points which have been extracted from the pages mentioned above:

1. The most probable values of M, A, and R are those that render the sum of the squares of the differences between the observed and computed yields a minimum, i.e., when they apply to the equation $[Y_1 - (M + AR^{x1})]^2 + [Y_2 - (M + AR^{x2})]^2 + [Y_3 - (M + AR^{x3})]^2 + [Y_4 - (M + AR^{x4})]^2 =$ Minimum, in which x1, x2, x3, and x4 represent the units of fertilizer (values of x) applied to the different plats, and Y_1, Y_2, Y_3, and Y_4 represent the corresponding yields.

2. The values of M. A, and R that reduce the equation to a minimum are obtained by differentiating the equation first with respect to M, then with respect to A, and finally with respect to R. The resulting normal equations are set equal to 0, and are solved for M, A, and R.

3. When these operations have been performed and the normal equations solved for the constants, we obtain the following equations:

$$M = 1/n\,[\Sigma Y + A\Sigma R^x] \qquad 1$$

in which n is the number of observation equations, and Σ indicates summation.

$$A_1 = \frac{n\Sigma\,(YR^x) - \Sigma Y \Sigma R^x}{(\Sigma R^x)^2 - n\Sigma R^{2x}} \qquad 2$$

From the normal equation of R, another normal equation for A is which is called A_2:

$$A_2 = \frac{n\Sigma\,(YxR^x) - \Sigma Y \Sigma\,(xR^x)}{\Sigma R^x \Sigma\,(xR^x) - n\Sigma\,(xR^{2x})} \qquad 3$$

It appears next to impossible to solve the last two equations simultaneously and thereby obtain values for A and R. A good method to follow is to try out a series of values of R and solve for A_1 and A_2.

These values are plotted against the corresponding R values, and two curves are drawn passing through the proper points. The intersection of the two resulting curves gives the correct values of A and R.

The second method is most easily applied to cases in which the increments of fertilizer are whole-numbered products of a common factor. For instance, if the quantities of the fertilizer applied were of this order: 75 pounds per acre, 100 pounds per acre, 250 pounds per acre, 500 pounds per acre, and 1,000 pounds per acre, the greatest common divisor is 25. The units of x in 25-pound increments in this series will therefore be as follows: 3, 4, 10, 20, and 40 units, respectively. The first method cannot be used for such a series of x units because, as we have learned previously, the values of x must increase by unity. However, while the second method has this distinct advantage over the first method, it cannot claim any speed whatever in the solution of its constants. The first method is recommended in all cases where fruit yields are obtained in which the fertilizers applied increased by unit increments, provided, of course, that none of the increase in fruit yields due to each increment of fertilizer is negative.

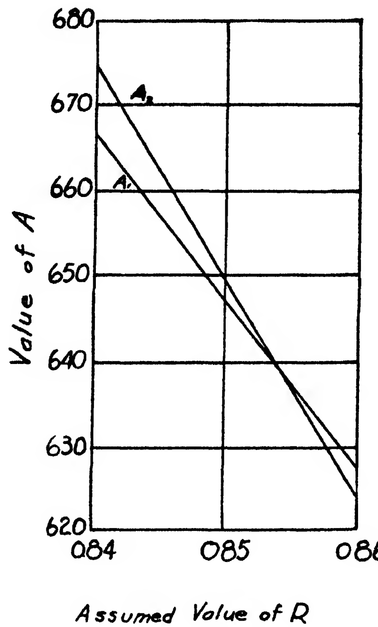

FIG. 1.—A graph of the values of A_1 and A_2 at various values of R. The best values of A and R are those found at the intersection of lines A_1 and A_2.

Since 25 pounds is the greatest common divisor of the amount of potash applied per acre in each treatment, in calculating the constants we can prepare the following table for the plant crop:

Pounds of potash per acre	Potash in units of 25 lbs. per acre	Actual tons of fruit per acre
125	5	16.21
200	8	17.27
300	12	18.17
400	16	18.58

The next step is to assume a value for R and solve the equations for A_1 and A_2 given in equations 2 and 3. This is done below where the various terms involved in both normal equations are indicated in tabulated form. Credit is due to Y. Kutsunai for having prepared a complete table of values of R^x, xR^x, and xR^{2x}. The values of R are from 0.1 to 0.99, while the values of x are from 0 to 20. These tables were prepared for the purpose of cutting down to a minimum the large amount of operations necessary on the calculating machine. The authors used these tables, and also adopted Kutsunai's and Caum's (6) systematized method of computation, which appears in a table form to avoid errors.

Assumed R = 0.85

x	Y	R^x	YR^x	xR^x	YxR^x	R^{2x}	xR^{2x}
5	16.21	0.4437	7.1924	2.2185	35.9619	0.1969	0.9844
8	17.27	0.2725	4.7061	2.1799	37.6469	0.0743	0.5940
12	18.17	0.1422	2.5838	1.7069	31.0144	0.0202	0.2428
16	18.58	0.0743	1.3805	1.1880	22.0730	0.0055	0.0882
	70.23	0.9327	15.8628	7.2933	126.6962	0.2969	1.9094

$$A_1 = \frac{n\Sigma\,(YR^x) - \Sigma Y \Sigma R^x}{(\Sigma R^x)^2 - n\Sigma R^{2x}} = \frac{4(15.8628) - (70.23)\,(0.9327)}{(0.9327)^2 - 4(0\ 2969)} =$$

$$\frac{63.4512 - 65.5035}{0.8699 - 1.1876} = \frac{-2.0523}{-0.3177} = 6.4599.$$

$$A_2 = \frac{n\Sigma(YxR^x) - \Sigma Y\Sigma\,(xR^x)}{\Sigma R^x\Sigma\,(xR^x) - n\Sigma\,(xR^{2x})} = \frac{4(126.6962) - 70{,}23(7.2933)}{0.9327(7.2933) - 4(1.9094)}$$

$$= \frac{506.7848 - 512.2085}{6.8025 - 7.6376} = \frac{-5.4237}{-0.8351} = 6.4947.$$

Upon trials with various R values, we have found the following:

R	A_1	A_2	Difference $A_1 - A_2$
0.84	6.6820	6.7572	− 0.0752
0.85	6.4599	6.4947	− 0.0348
0.86	6.2813	6.2437	+ 0.0376

Since the difference $A_1 - A_2$ passes from a negative to a positive value in going from R values of 0.85 to 0.86, it is evident that the true R value lies between these points. In order to determine its value more accurately, the values of A_1 and A_2 are plotted against R values of 0.85 and 0.86 on coordinate paper, as shown in Fig. 1. If a line is drawn joining the two A_1 values and another joining the two A_2 values, the point of intersection of these lines projected to the x axis will give a true value of R. The value is 0.854. The above

method is described by Kutsunai and Caum (6). By taking proportional parts we find that when $R = 0.854$, the average value for A is 6.38. With these values, we proceed to determine M, or the maximum yield possible. The formula is $M = 1/4(\Sigma Y + \Sigma AR^x)$.

We first solve for ΣAR^x, as follows:

x	AR^x	AR^x
5	$6.38(0.854)^5$	2.90
8	$6.38(0.854)^8$	1.81
12	$6.38(0.854)^{12}$	0.96
16	$6.38(0.854)^{16}$	0.48
	$\Sigma AR^x =$	6.19

$M = 1/4(70.23 + 6.19) = 19.10$ tons per acre. Therefore, our yield equation becomes

$$Y = 19.10 - 6.38(0.854)^x \qquad 4$$

in which x is in units of 25 pounds of potash per acre.

The value of R changes when the units are changed. For example, the ratio R when x is in units of 25 pounds per acre is not the same R as when x is in units of 50 pounds per acre, or 75 pounds per acre, or 100 pounds per acre. To find the value of R expressed in terms of a new set of units of x, when the value of R is already given in terms of some other units of x, we simply raise the ratio to that power in which the original unit is contained in the new unit of fertilizer; i.e., if the ratio is R_1 when x is in units of 25 pounds, then the raito when x is in units of 50 pounds will be $R_1^{50/25}$ or R_1^2.

We prefer to have our yield equation in a form in which x is in units of 100 pounds of fertilizer. Since the yield equation just derived above is in the form in which x is in units of 25 pounds of potash, we must change the ratio 0.842. This is accomplished by solving the term $(0.854)^{100/25}$ or $(0.854)^4$. This term upon calculation gives a ratio of $R = 0.538$ in which x is in terms of 100 pounds of potash. Hence, the equation for the plant crop will finally read

$$Y = 19.10 - 6.38(0.538)^x \qquad 5$$

Using the first method of Spillman and an interpolated yield of 15.65 tons per acre with 100 pounds of K_2O, an equation for the yield curve was calculated, as follows:

$$Y = 19.00 - 6.70(0.503)^x \qquad 6$$

The two yield equations derived for the plant crop by methods one and two are not identical but vary little from each other. We can compare the fit of equations 5 and 6 by calculating the sum of the squares of the differences between the calculated and observed values. Doing this we find a sum of 0.0179 for equation 5 and 0.0420 for equation 6, indicating that equation 5 is a better fit.

The same procedure by the second method may be used in solving for M, A, and R for the cycle crop, but requires a little more care. The application of 245 pounds of potash per acre is out of alignment with the other increments of 320, 420, and 520 pounds. Five is the

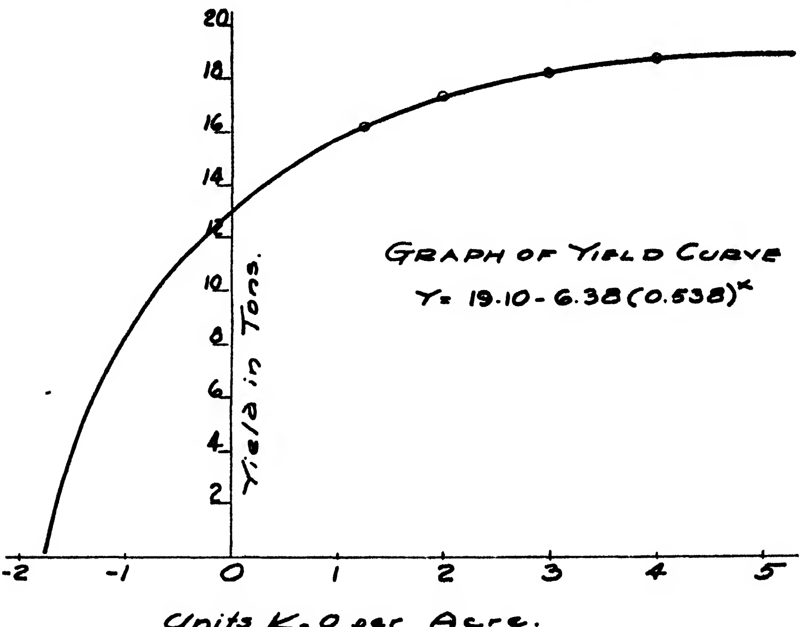

FIG. 2.—A graph of the yield curve for the plant crop.

greatest common divisor for this series. The series using 5 as a factor would lead to such high powers of R that we will not attempt to use it.

The next possibility is to take our origin at (20, Y) with x in units of 100 pounds. This furnishes a series of x in the following order: $2.2\bar{5}$, 3, 4, and 5. With this series and the corresponding yields of 39.72, 42.44, 45, 36, and 46.88 tons per acre, we proceed to solve for the constants. The steps are exactly like those in the previous example. On performing them we find the yield equation to be

$$Y = 49.95 - 26.27(0.654)^x \quad 7$$

The equation of the yield curve as given in 7 refers to the origin at (0.2, 0). The equation of the yield curve can be corrected so that it refers to the origin at (0,0) by substituting for x in equation 7 the value x — 0.2.

$$\begin{aligned} \text{Therefore, } Y &= 49.95 - 26.27(0.654)^{x-0.2} \\ &= 49.95 - 26.27(0.654)^x(0.654)^{-0.2} \\ &= 49.95 - 28.55(0.654)^x \quad 8 \end{aligned}$$

Curves have been constructed using the yield equations 5 and 8 for the plant and cycle crops, respectively, as determined by the second method. These are shown in Figs. 2 and 3. The circles on the graph represent the observed yields.

RESULTS DERIVED FROM YIELD CURVES

Yields obtained with various fertilizer applications can be expressed in tabular form. The trend of results is indicated more clearly however, by graphs or yield curves. These can be accurately constructed so as to be a "best fit" and the equations of such curves can then be used for a number of calculations which will often yield much additional information about the experiment. An obvious calculation to make in using a yield curve equation is the point of economical fertilization at given prices for produce and fertilizer. This calculation will appear in another paper. We can also calculate the quantity of potash furnished by the soil.

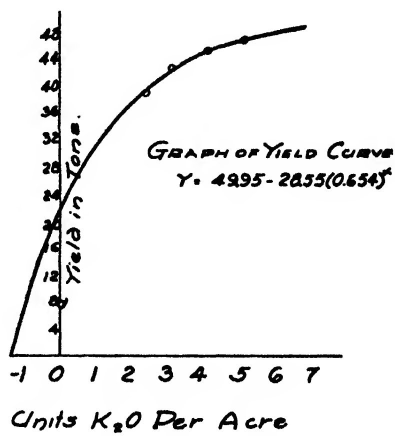

FIG. 3.—A graph of the yield curve for the cycle crop.

THE QUANTITY OF GROWTH FACTOR (POTASH) FURNISHED BY THE SOIL

We can calculate from the yield equations that had no fertilizer been applied, i.e., when $x = 0$, the yields would have been 12.72 and 21.40 tons per acre for the plant and cycle crops, respectively. In other words, the soil's natural fertility was sufficient to produce these yields. It is desirable to know the amount of potash that was available in the soil to produce these yields, and we can do this by reading the points of intersection of the yield curve with the x axis. Thus, in Fig. 2, the yield curve crosses the y axis erected at $x = 0$ at the point where $Y = 12.72$ tons. This yield was 12.72 tons or would have been within reasonable limits, and was produced without potash fertilization. Extending the curve at the same rate of curvature into the second quadrant, we find that the yield curve crosses the x axis at the value $-1.78x$. At this point $Y = 0$, meaning the yield would be 0. With a plant which must produce a considerable mass of stem and leaves before it can fruit this concept is slightly inaccurate.

The quantity of fertilizer represented by the distance from the origin to the intersection of the yield curve with the x axis is called by Mitscherlich (11) the "b" value. Since Spillman has no symbol for this value, we have used that of Mitscherlich. The magnitude of this b value can be determined by setting $Y = 0$ in the yield equation and solving for x, for instance,

$$Y = 19.10 - 6.38(0.358)^x$$

Setting $Y = 0$, we have $0 = 19.10 - 6.38(0.538)^x$ or $(0.538)^x = \frac{19.10}{6.38}$, hence $x = \frac{\log 19.10 - 6.38}{\log (0.538)} = -1.78$ units or 178 pounds.

We here have a method of calculating the store of available nutrient in a soil which does not depend on chemical tests. Yield data from a fertilizer experiment and a computing machine are all that are necessary.

It must be remembered, as Mitscherlich has pointed out, that the b value represents the amount of plant food apparently available in the soil; that it is given in the same units of availability as the fertilizer used (in this case 100 pounds K_2O from potassium sulfate); and that it is contained in the soil of 1 acre to the mean effective root depth.

Were it not for the long time necessary to obtain yields by field experiment, the mathematical treatment of the harvest results offers a very convenient method of measuring the fertility of the soil. The alternative to overcome the time factor is to devise pot experiments in which fast-growing crops are used. The crops must either be of the kinds, which, when the yields are treated in the same mathematical way, supply the same R values, or kinds in which a definite relationship between them and the pineapple has been determined.

The chemical or greenhouse test which will yield the same b values as have been obtained in the field by field experiment would be a test accurately gauging the soil's native store of available nutrients. The b values can thus serve as a very good criterion of the reliability of chemical tests.

We can reasonably expect to get quite different b values in the field than in the laboratory for a plant food which is gradually liberated, as is nitrogen and possibly potash. Especially is this true for crops requiring 2 years to attain maturity, as in the case of the pineapple.

SUMMARY

1. The authors have taken the yield data from one field experiment involving potash fertilization on pineapples and constructed yield curves. Such yield curves have been constructed for the plant crop

and for the cycle crop, which in this case consists of plant and first ratoon.

2. The authors have made a number of yield curves and others, as well as the ones here submitted, convince them that yield increases attributed to fertilization very often follow mathematical expressions such as those set up by Mitscherlich and Spillman.

3. Attempts have been made to incorporate in this paper the mathematical methods of securing the best fit for yield curves and for other derived values so that they would be available in a widely circulated journal in the English language. The authors wish to give credit to other workers for many of the mathematical methods used.

4. It has been shown how the quantity of plant food arising from the soil can be calculated from yield curves. This constitutes a method of soil analysis which involves only yield data and computations upon them. This quantity, called by Mitscherlich the "b" value, may possibly serve as a good criterion as to the reliability of chemical soil analyses.

5. Any indicator crop used in the greenhouse will correctly forecast results in the field if on the same soil the R values are identical or if they always bear a constant value to each other. Yield curves thus serve to evaluate the suitability of indicator crops. This is of especial importance with large crops having a long growing season, such as pineapples, sugar cane, bananas, and tree crops.

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THE EFFECT OF THE LACK OF AVAILABLE MANGANESE IN THE SOIL ON CROP YIELDS[1]

T. E. ODLAND and F. K. CRANDALL[2]

In several previous papers from this Station (2, 3),[3] attention has been called to the effect of a lack of manganese on several different crops. The lack of available manganese is indicated by a typical chlorosis in some of the crops and certain characteristic symptoms in other crops. In this paper results of further field tests with different crops will be presented.

The literature on the subject of manganese deficiency in soils has recently been reviewed by Carlyle (1) and by Willis (5). In general, a fairly close correlation has been found between heavy liming and indications of manganese deficiency. At the Rhode Island Station the lack of available manganese, as shown by certain crops, has always been the most pronounced on plats where the soil had been limed to neutrality or near neutrality. In some cases other investigators have suggested different possible causes for the development of manganese deficiencies in the soil.

The soil at this station where these experiments are being con-

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[3]Reference by number is to "Literature Cited," p. 625.

ducted is a black silt loam with a comparatively high degree of acidity before being limed. Manganese deficiency develops with a number of crops where the soil is limed to near the neutral point.

In Table 1 are presented the yields of spinach, beets, and lettuce obtained with and without manganese applications on plats where the soil has been limed to about neutrality. These crops are grown in a 3-year market garden rotation. The plats used are 1/30 acre in size. On the plats where manganese applications were made one-half of a plat received manganese while the other half did not.

TABLE 1.—*Yields per acre of spinach, table beets, and head lettuce with and without manganese applications at the Rhode Island Agricultural Experiment Station.*

Crop	Treatment	Unit	Year				
			1927	1928	1929	1930	1931
Spinach (spring)	Manganese	Bushels	——	1,995	1,500	1,875	660
Spinach (spring)	No manganese	Bushels	——	1,061	770	1,560	490
Spinach (fall)	Manganese	Bushels	1,565	575	1,060	1,425	1,545
Spinach (fall)	No manganese	Bushels	670	405	570	1,310	1,320
Beets (spring)	Manganese	Dozen bunches	1,855	1,305	1,660	1,875	1,575
Beets (spring)	No manganese	Dozen bunches	1,715	1,075	1,495	1,935	1,625
Beets (fall)	Manganese	Bushels	354	288	108	428	432
Beets (fall)	No manganese	Bushels	116	177	79	431	391
Lettuce	Manganese	Boxes	1,783*	210	293	600	376
Lettuce	No manganese	Boxes	955*	120	260	536	316

*1926 yields; crop a failure in 1927.

As may be seen from these results, there was a very striking response to manganese applications on fall spinach during the 1927–29 period, and on the spring-planted spinach in 1928 and 1929. The response to manganese has also been considerable during the last 2 years, but not nearly as striking as during the first 3 years. The reason for this is not entirely clear.

Both spring and fall crops of beets have responded much in the same manner as the spinach crop in that generally more striking results were obtained from manganese applications during the first 3 years than during the last 2 years of the tests. In three out of four instances in the last 2 years the yield has been as high without manganese applications as with it. Here again, the reason is not clear. Whether this is a case of a climatic factor or some other factor needs to be determined.

The yield of head lettuce has consistently been increased by applications of manganese. The response during the last 3 years of the experiment have not been as striking as in 1926 and in 1928.

A possible explanation of the lessened response to manganese in the last few years in these tests may be that more of this element is being supplied in the manure and compost than was formerly the case. On all of these plats manure-compost is applied each spring at the rate of 16 tons per acre. A larger percentage of vegetable compost has been used in the mixture in the last 3 years than was formerly the case.

TABLE 2.—*Yields of different crops grown with and without manganese on the liming materials experiment.*

Crop	Treatment	Unit	Plat number and lime treatment				
			74 $Ca(OH)_2$	76 $MgCO_3$	78 $CaCO_3$	80 $Mg(OH)_2$	82 No lime
			1929				
Sweet corn	Manganese	Lbs.	8,731	9,711	9,334	9,439	10,117
Sweet corn	No manganese	Lbs.	5,500	7,806	6,339	6,993	7,903
			1930				
Hay......	Manganese	Tons	1.64	2.25	2.00	2.34	1.07
Hay......	No manganese	Tons	1.42	1.79	1.81	2.04	0.76
			1931				
Spinach...	Manganese	Bus.	1,859	3,030	2,346	2,621	56
Spinach...	No manganese	Bus.	1,344	1,336	1,372	1,292	30
Beets......	Manganese	Bus.	139	133	168	144	12
Beets.....	No manganese	Bus.	76	98	77	65	3
Potatoes ..	Manganese	Bus.	92	150	151	144	160
Potatoes...	No manganese	Bus.	76	120	104	127	159
Tomatoes	Manganese	Bus.	291	556	528	546	691
Tomatoes	No manganese	Bus.	269	522	541	515	550
Mangels...	Manganese	Tons	17.88	16.46	16.12	20.26	11.22
	No manganese	Tons	7.12	5.24	6.08	11.29	4.97

In another experiment where different forms of lime are compared and where no manure is applied further results on the response of different crops to manganese have been obtained. The lime plats are approximately neutral in reaction, while Plat 82, the unlimed check, shows a pH of approximately 4.5. The yields obtained with the different crops during the last 3 years are presented in Table 2.

Sweet corn in 1929 showed a very high response to manganese, being increased by practically a half on the limed plats and by about 25% on the unlimed plat. No manganese was applied for the hay

crop in 1930. The residual effects of the manganese applied in the preceding several years were evident.

During 1931 five different crops were grown on these plats. The spinach and beet crops were practically total failures on the unlimed plat. On the limed plats these two crops were very much improved by the manganese applications.

Potatoes did not do well on either the heavily limed or the acid plats. On the limed plats they were benefited by the manganese but not on the unlimed plat. The yields varied from 76 to 160 bushels per acre.

Tomatoes did not show any marked response to manganese on any of the plats. On one of the plats the average yield was smaller on the manganese side than on the other. These results indicate that under our conditions this crop is not nearly as sensitive to manganese deficiency as spinach, mangels, or beets. Schreiner and Dawson (4), on the other hand, have found tomatoes to be very sensitive to manganese deficiency in Florida.

The mangels showed a very marked increase in yield due to manganese on all plats, including the acid one. The yields ranged from 4.97 to 20.26 tons per acre.

These results give further data on the response to manganese of several crops not heretofore used in these tests at this station. It is evident that under the same soil conditions different crops will respond differently to manganese deficiency in the soil.

In view of these experiments and those reviewed in the papers cited, there are apparently a number of factors connected with this problem that need further study. The question of the seasonal fluctuation of manganese deficiency as shown by different experiments needs to be studied. In a number of the experiments reported, a manganese deficiency showed up on spring-planted spinach but not on the fall crop, and *vice versa*. The relative importance of manganese to different crops also needs to be investigated further. No doubt many crops that have not been tested under field conditions may show a strong response to small additions of manganese under conditions similar to the above. The experiments have demonstrated that there is a considerable difference between different crops in respect to their manganese requirements.

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ROOT DEVELOPMENT IN HARDY AND NON-HARDY WINTER WHEAT VARIETIES[1]

W. W. WORZELLA[2]

Winter wheats occupy about 70% of the total wheat acreage of the United States, according to the varietal survey of 1924 by Clark, *et al.* (1).[3] In regions where the winters are not too severe, winter wheat is generally more productive than spring wheat because it ripens earlier and as a result is less exposed to injury from rust and drought. However, in various wheat-growing sections the winters are long, cold, and dry, and frequently cause severe losses from winter killing. During the 28-year period from 1901 to 1928, the average annual abandonment of winter wheat acreage of the United States was about 11%, due largely to winter killing.

The extreme winter killing of 1927–28 in the soft winter wheat crop has emphasized the fact that soft wheats, in general, are not winter hardy. There are several factors that may cause winter injury to wheat. It is commonly believed that winter injury to the winter wheat crop in Indiana is due largely to heaving resulting from alternate freezing and thawing of the soil. As a consequence the plants are lifted and in many instances some or all of the roots are broken: At best, the roots are exposed to unfavorable weather conditions. Varieties of wheat vary greatly, however, in respect to the extent of winter injury from this cause. It has been observed repeatedly that certain varieties of the hard red winter class are able to withstand these conditions and do not winter kill as readily as the soft

[1]Contribution from Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Part of a thesis submitted to Purdue University in partial fulfillment of the requirement for the degree of master of science in agriculture. Also presented at the annual meeting of the Society held in Chicago, Ill., November 20, 1931. Received for publication December 8, 1931.

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[3]Reference by number is to "Literature Cited," p. 637.

wheats. It would seem, therefore, that these hardy varieties possess certain peculiar characteristics which enable them to survive the rigors of Indiana winters. The purpose of this investigation was to make a detailed study of the root systems of several varieties of hardy and non-hardy winter wheats in order to study differences, if any, in the nature and development of the roots, and to ascertain the relation between the difference that may be found and resistance to winter killing from heaving. The study was made during 1929–30 and 1930–31 on eight varieties of winter wheat grown under natural field conditions.

REVIEW OF LITERATURE

Numerous studies have been made as to the influence of fertilizer, moisture content, aeration, time of seeding, and other factors on the development of root systems in wheat, but few data, so far as the writer is aware, are available on the actual development of roots during fall, winter, and spring. King (3) studied the distribution of roots in winter wheat and observed roots penetrating to a depth of almost 4 feet. Walworth and Smith (4) report variations existing in the number of seminal roots in wheat, and state that different varieties have their characteristic tendencies toward a higher or lower number. Weaver, Kramer, and Reed (5) made a detailed study of the development of roots in Kanred wheat and showed that as the wheat went into the winter some of the seminal roots reached a depth of 4 feet. The adventitious roots averaged 7 inches in length at this time. In mature plants the roots reached a depth of 5 to 7 feet. Janssen (2) studied the progressive root development on a series of five plantings and observed on November 26 that the majority of roots reached depths varying from 12 to 35 cm., according to the date of seeding. His work also showed that old fall roots do not continue active growth in the spring but that new roots originate from the crown of the plant.

METHODS AND MATERIALS

The technic followed in this investigation was that used extensively by Weaver (5) and his co-workers. The method adopted consisted in digging a trench 10 feet long, 2.5 feet wide, and to a depth exceeding the deepest roots, which varied from 3 to 7 feet depending upon the age of the plants. At one end of this trench another short trench was dug at right angles to the main one so that two surfaces of the soil were exposed to the worker. An ice pick and a sharp-pointed crochet hook were used to remove the soil from about the roots embedded in the wall of the trench. As the roots were exposed exact measurements were made and drawings were mapped on cross-section paper showing the natural position of each root.

The root systems of eight varieties of hardy and non-hardy wheats were studied during two successive seasons, 1929–30 and 1930–31. Four of the varieties, namely, Fultz, Michigan Amber, Rudy, and Red Cross, are non-hardy, whereas the remaining four, Kanred, Kharkof, Michikof, and Purkof, are relatively hardy when grown under Indiana conditions. The root systems of Fultz and Kanred were examined at 20-day intervals until winter set in and again in February and April, whereas the other six varieties were studied only in the fall and in the spring.

TABLE 1.—*Monthly mean temperature and precipitation at Lafayette, Indiana.*

Month	1929–30		1930–31	
	Temperature, °F	Rainfall, in.	Temperature, °F	Rainfall, in.
Sept	66.6°	1.56	69.0°	3.80
Oct	55.3°	4.08	54.5°	0.89
Nov.	38.4°	1.81	47.3°	2.34
Dec.	29.7°	5.94	31.5°	0.24
Jan	23.4°	6.43	33.4°	1.01
Feb.	41.1°	2.25	38.7°	1.33
March	39.8°	1.94	37.3°	2.53
Total precipitation		24.01		12.14

EXPERIMENTAL RESULTS

TEMPERATURE AND PRECIPITATION

The two seasons during which root development was studied were very different with respect to temperature and precipitation. Table 1 shows that the 1929–30 season was cooler and wetter than the season of 1930–31. It will be noted that the average monthly temperature for the months of September, November, December, and January was much higher in the second season than in the first. The total precipitation for the months of September to March, inclusive, was 24.01 inches for the 1929–30 season and only 12.14 inches for 1930–31. In view of the fact that the two seasons were so different it is not surprising that large differences were found in the amount of top growth and root development.

PROGRESSIVE ROOT DEVELOPMENT

In Tables 2, 3, and 4 are given the average length, depth, and spread per plant of the seminal and adventitious roots at various stages of development during the two seasons of 1929–30 and 1930–31. Figs. 1, 2, 3, 4, 5, and 6 show free-hand drawings of the root systems of Fultz and Kanred at different stages of development. During the 1929–30 season, which was cool and wet, the root growth was slow

TABLE 2.—*Average length of seminal and adventitious roots at different stages of development from wheat planted October 1 under field conditions.**

Date	Non-hardy varieties								Hardy varieties							
	Fultz		Michigan Amber		Rudy		Red Cross		Kanred		Kharkof		Michikof		Purkof	
	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious
1929–30																
Oct. 20	2.9	—	—	—	—	—	—	—	3.5	—	—	—	—	—	—	—
Nov. 9	6.3	1.0	—	—	—	—	—	—	5.0	0.4	—	—	—	—	—	—
Nov. 28	6.8	2.4	—	—	—	—	—	—	7.5	1.4	7.4	1.0	—	—	—	—
Dec. 14	12.4	2.9	9.6	1.6	11.2	2.5	11.0	2.4	12.6	1.5	—	—	11.1	2.7	14.8	2.1
Feb. 22	12.9	2.2	—	—	—	—	—	—	12.5	1.4	—	—	—	—	—	—
Apr. 3	24.0	5.6	24.4	5.1	20.5	4.8	23.6	4.3	23.2	4.0	23.5	4.4	25.0	4.7	26.0	4.7
1930–31																
Oct. 20	4.0	—	—	—	—	—	—	—	4.5	—	—	—	—	—	—	—
Nov. 8	9.6	0.6	—	—	—	—	—	—	9.5	0.5	—	—	—	—	—	—
Dec. 2	16.8	1.8	—	—	—	—	—	—	15.2	1.2	—	—	—	—	—	—
Dec. 15	20.9	2.5	19.1	2.1	19.6	1.9	19.5	2.1	19.9	2.0	19.1	1.8	19.1	2.2	20.4	1.9
Feb. 19	24.4	4.5	—	—	—	—	—	—	23.9	3.6	—	—	—	—	—	—
Mar. 30	31.1	5.8	29.4	5.0	31.4	5.4	31.7	5.9	31.7	4.4	27.6	3.0	31.4	3.5	30.1	5.9

*Measurements were made in inches on five plants from each variety studied.

TABLE 3.—*Average depth of seminal and adventitious roots at different stages of development from wheat planted October 1 under field conditions.**

Date	Non-hardy varieties								Hardy varieties							
	Fultz		Mich. Amber		Rudy		Red Cross		Kanred		Kharkof		Michikof		Purkof	
	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious
								1929–30								
Oct. 20	3.3	—	—	—	—	—	—	—	4.0	—	—	—	—	—	—	—
Nov. 9	5.2	1.0	—	—	—	—	—	—	5.1	1.0	—	—	—	—	—	—
Nov. 28	5.3	2.0	—	—	—	—	—	—	7.5	1.8	7.0	1.4	—	—	—	—
Dec. 14	11.2	3.0	8.1	1.8	9.6	2.5	10.1	2.0	12.4	1.8	—	—	10.2	2.2	15.2	1.8
Feb. 22	11.6	1.5	—	—	—	—	—	—	12.3	1.5	—	—	—	—	—	—
Apr. 3	22.0	5.1	21.7	4.1	18.8	3.8	21.8	3.6	21.5	3.2	22.3	4.4	23.6	4.0	24.0	4.2
								1930–31								
Oct. 20	3.6	—	—	—	—	—	—	—	4.7	—	—	—	—	—	—	—
Nov. 8	8.2	1.0	—	—	—	—	—	—	9.3	1.0	—	—	—	—	—	—
Dec. 2	15.7	1.9	—	—	—	—	—	—	14.7	1.3	—	—	—	—	—	—
Dec. 15	19.1	2.7	17.1	2.3	17.1	2.2	17.8	2.4	18.3	2.3	17.8	2.1	18.0	2.4	.18.6	2.2
Feb. 19	23.0	3.2	—	—	—	—	—	—	22.6	3.4	—	—	—	—	—	—
Mar. 30	29.1	5.4	27.0	4.4	29.0	5.0	30.0	5.4	30.5	3.6	26.0	2.4	30.0	3.0	29.0	5.2

*Measurements were made in inches on 5 plants from each variety studied

Table 4.—*Average spread of seminal and adventitious roots at different stages of development from wheat planted October 1 under field conditions.**

Date	Non-hardy varieties								Hardy varieties							
	Fultz		Mich. Amber		Rudy		Red Cross		Kanred		Kharkof		Michikof		Purkof	
	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious	Seminal	Adventitious
								1929–30								
Oct. 20	2.5	—	—	—	—	—	—	—	2.4	—	—	—	—	—	—	—
Nov. 9	3.9	0.8	—	—	—	—	—	—	2.7	0.3	—	—	—	—	—	—
Nov. 28	4.6	2.0	—	—	—	—	—	—	3.5	1.1	4.4	1.0	—	—	—	—
Dec. 14	6.5	2.7	5.5	1.2	5.8	1.7	5.1	2.1	5.3	1.4	—	—	5.4	2.4	5.6	2.0
Feb. 22	6.5	1.7	—	—	—	—	—	—	5.1	1.0	—	—	—	—	—	—
Apr. 3	7.4	3.6	7.5	3.5	6.9	3.2	7.0	3.0	6.3	2.5	6.5	3.1	6.5	2.9	6.8	3.0
								1930–31								
Oct. 20	2.9	—	—	—	—	—	—	—	2.5	—	—	—	—	—	—	—
Nov. 8	4.7	0.6	—	—	—	—	—	—	3.7	0.5	—	—	—	—	—	—
Dec. 2	6.1	1.8	—	—	—	—	—	—	4.9	1.2	—	—	—	—	—	—
Dec. 15	6.7	2.5	6.7	2.1	6.7	1.9	6.3	2.1	5.6	2.0	5.8	1.8	5.5	2.2	5.8	1.9
Feb. 19	7.2	3.6	—	—	—	—	—	—	6.1	2.7	—	—	—	—	—	—
Mar. 30	7.4	3.4	7.3	3.1	7.5	3.4	7.5	3.5	6.5	2.5	6.5	2.4	6.7	2.9	6.8	3.4

*Measurements were made from the base of the plant in inches on 5 plants from each variety studied.

with no increase from December 14 to February 22 (Figs. 4 and 5), while in 1930–31, which was warmer and drier, growth continued

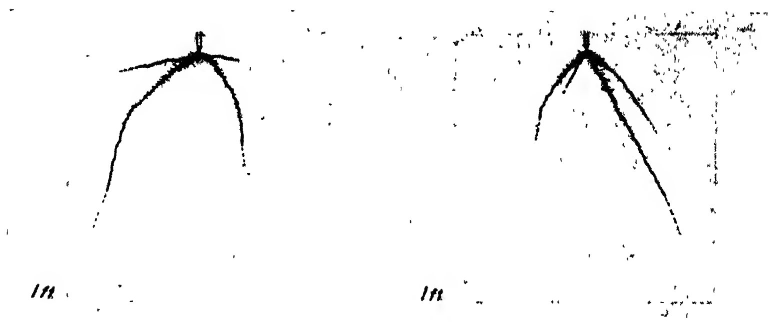

FIG. 1.—Root systems of Fultz (left) and Kanred (right) on Oct. 20, 20 days after planting. Solid line, 1929 growth; solid and broken line, 1930 growth.

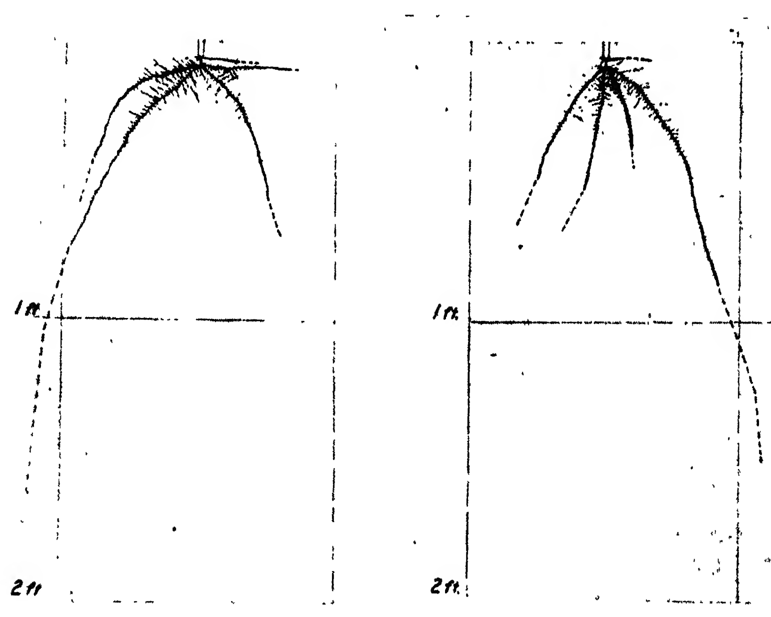

FIG. 2.—Root systems of Fultz (left) and Kanred (right) on Nov. 9, 40 days after planting. Solid line, 1929 growth; solid and broken line, 1930 growth.

throughout the winter and the plants showed approximately twice as great root development as those of the previous season. There appears to be no significant differences as to the average length and depth of seminal roots of the eight varieties studied, however the

non-hardy varieties show a greater average spread from the base of the plant than the hardy varieties (Table 4) and thus show two quite distinct types of root systems.

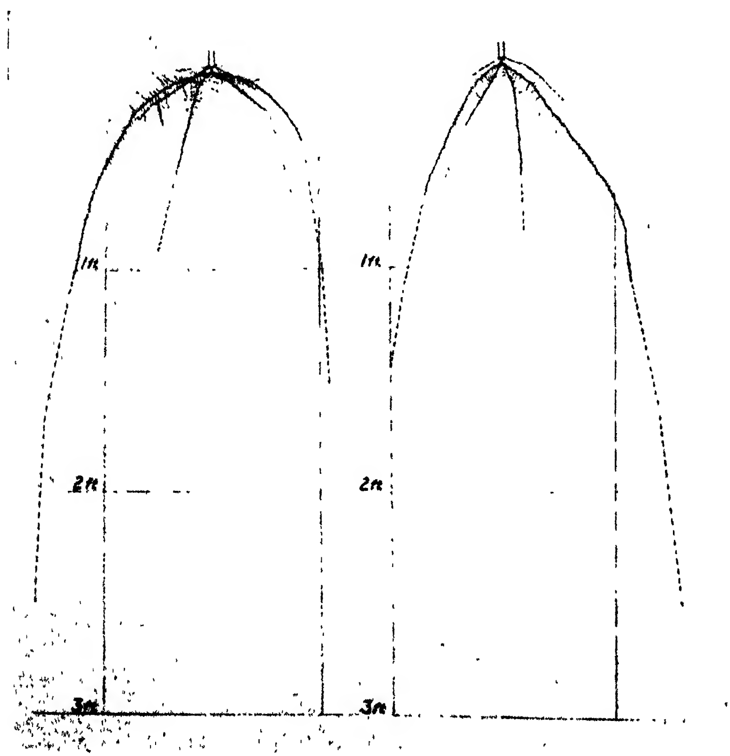

FIG. 3—Root systems of Fultz (left) and Kanred (right) on Nov. 28, 1929, and Dec. 2, 1930, respectively, 59 or 63 days after planting. Solid line, 1929 growth; solid and broken line, 1930 growth.

Most of the seminal roots of the four non-hardy winter wheat varieties develop almost horizontally in the early stages of growth with most of the spread remaining at comparatively shallow depths then turning downward, while other roots run obliquely outward. In general, in the hardy varieties of winter wheat most of the seminal roots run obliquely outward or straight downward with very little spread near the surface. This was true of the three varieties Kanred, Michikof, and Purkof, however, in Kharkof, also a hardy variety, the seminal roots followed a course intermediate between that found in a typical non-hardy and the other hardy varieties.

Twenty days after planting (Fig. 1) the wheat plants did not show any adventitious roots, however, at 40 days (Fig. 2) an average of

three adventitious roots per plant was found. Figs. 3, 4, and 5 show further that the adventitious roots develop slowly in the fall. Their number and length is greatly increased, however, in the spring (Fig. 6) In general, the non-hardy varieties possess a greater number of

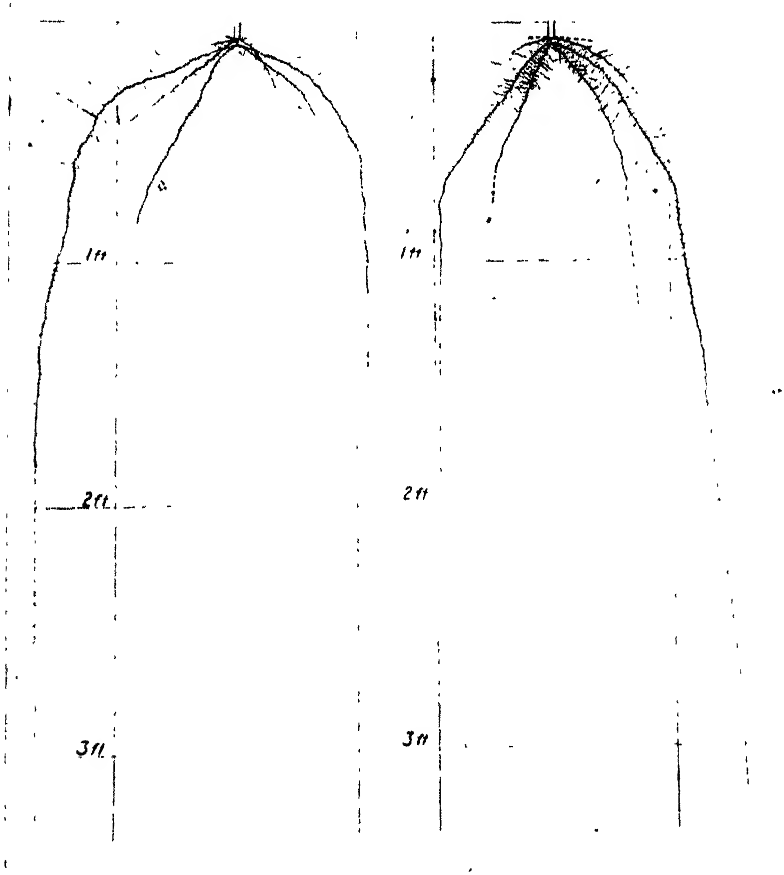

FIG. 4.—Root systems of Fultz (left) and Kanred (right) on Dec. 14, 75 days after planting. Solid line, 1929 growth, solid and broken line, 1930 growth.

adventitious roots which are longer than those of the hardy varieties. The roots of mature wheat plants were examined on June 26, 1931, and it was found that some roots penetrated to a depth of 70 inches.

Table 5 gives the average dry weight in grams of the shoots and roots per plant at various stages of development. The weight of shoots per plant is based on the average of 12 plants, whereas the weight of roots per plant is based on the average of 5 plants. As only

TABLE 5.—*Average dry weight in grams of shoots and roots per plant at various stages of development from wheat planted October 1 under field conditions.*

Date	Non-hardy varieties								Hardy varieties							
	Fultz		Mich. Amber		Rudy		Red Cross		Kanred		Kharkof		Michikof		Purkof	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
								1929–30								
Oct. 20	0.015	0.009	—	—	—	—	—	—	0.014	0.008	—	—	—	—	—	—
Nov. 9	0.042	0.015	—	—	—	—	—	—	0.032	0.012	—	—	—	—	—	—
Nov. 28	0.060	0.020	—	—	—	—	—	—	0.045	0.015	0.043	0.015	—	—	—	—
Dec. 14	0.085	0.032	0.074	0.030	0.082	0.030	0.071	0.029	0.054	0.027	—	—	0.061	0.030	0.068	0.030
Feb. 22	0.076	0.033	—	—	—	—	—	—	0.048	0.025	—	—	—	—	—	—
Apr. 3	0.191	0.078	0.204	0.071	0.180	0.077	0.171	0.068	0.132	0.052	0.163	0.072	0.162	0.070	0.184	0.082
								1930–31								
Oct. 20	0.025	0.013	—	—	—	—	—	—	0.038	0.014	—	—	—	—	—	—
Nov. 8	0.074	0.026	—	—	—	—	—	—	0.071	0.025	—	—	—	—	—	—
Dec. 2	0.116	0.062	—	—	—	—	—	—	0.100	0.056	—	—	—	—	—	—
Dec. 15	0.123	0.074	0.110	0.072	0.138	0.072	0.123	0.070	0.107	0.068	0.106	0.058	0.093	0.069	0.109	0.070
Feb. 19	0.147	0.082	—	—	—	—	—	—	0.125	0.076	—	—	—	—	—	—
Mar. 30	0.170	0.086	0.167	0.078	0.182	0.088	0.184	0.082	0.166	0.081	0.158	0.063	0.170	0.082	0.201	0.086

a few plants were used to determine the dry weight, no definite conclusions can be made; however, the data indicate that the non-hardy varieties produce more top growth in the fall and early winter, from October 1 to February 22, than the hardy varieties.

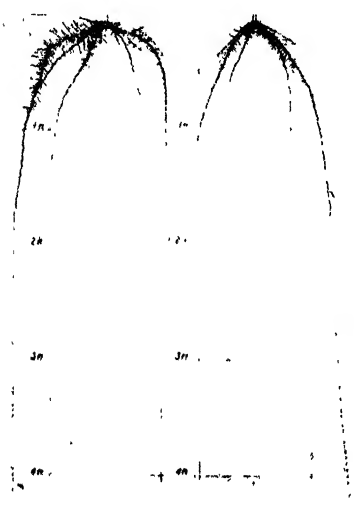

FIG. 5.—Root systems of Fultz (left) and Kanred (right) on Feb. 22. Solid line, 1929-30 growth; solid and broken line, 1930-31 growth.

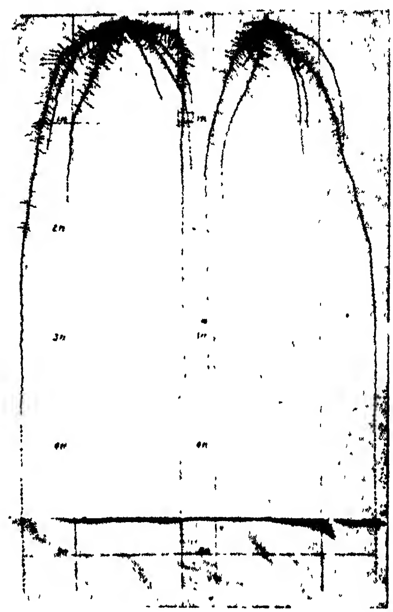

FIG. 6.—Root systems of Fultz (left) and Kanred (right) in April 3. 1930, and March 30, 1931, respectively. Solid line, 1929-30 growth; solid and broken line, 1930-31 growth.

SUMMARY

1. The root systems of four non-hardy and four hardy varieties of winter wheats were examined at various intervals during 1929–30 and 1930–31 when grown in the field.

2. Seasonal conditions greatly influenced the amount of root development in fall and early spring in winter wheat. In a warm and dry season the roots grew more rapidly and penetrated to lower depths than in a cooler and wetter season.

3. When grown under field conditions winter wheats possess two types of root systems. In the non-hardy varieties studied many of the seminal roots develop almost horizontally in the early stage of growth, then turn downward, while other roots run obliquely outward. In general, in the hardy varieties studied most of the seminal

roots run obliquely outward or straight downward. Adventitious roots do not show a great deal of development in the fall, but they increase greatly in number and growth in the spring.

4. Non-hardy varieties of winter wheat show a greater top growth in the fall and early winter, from October 1 to February 22, than the hardy varieties.

5. In mature plants some of the roots penetrated to a depth of 70 inches.

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A DEVICE FOR USE IN DETERMINING THE MOISTURE CONTENT OF DRYING FORAGES[1]

EDWIN R. HENSON[2]

The usual method of determining the moisture content of forage crops in experimental work is by taking shrinkage samples of the material. The methods of taking, handling, and using these samples have been tested and described by Arnay (1),[3] McRostie and Hamilton (2), Vinall and McKee (3), McKee (4), and Odland and Garber (5). Three samples, varying from about 5 pounds of fresh-cut material to 2 pounds of field-cured material are generally used. Often the material is air-dried, weighed, then ground, and representative samples completely dried in an oven. The original moisture content is determined from the loss in weight.

It is evident that considerable time must elapse from the time of sampling until the moisture content can be known. This delay renders the use of such methods impractical where the next field operation

[1]Contribution from Department of Farm Crops, Iowa State College, Ames, Iowa. Received for publication January 6, 1932.

[2]Associate Professor.

[3]Reference by number is to "Literature Cited," p. 641.

in handling the material is to be introduced at a particular stage in the curing or drying process. In experimental studies on methods of curing and storing hay at the Iowa Station, it was necessary that the moisture content of the alfalfa hay be known continuously during the curing process so that subsequent operations could be instigated at the proper degree of curing, and that hay could be placed in storage with a definite moisture content.

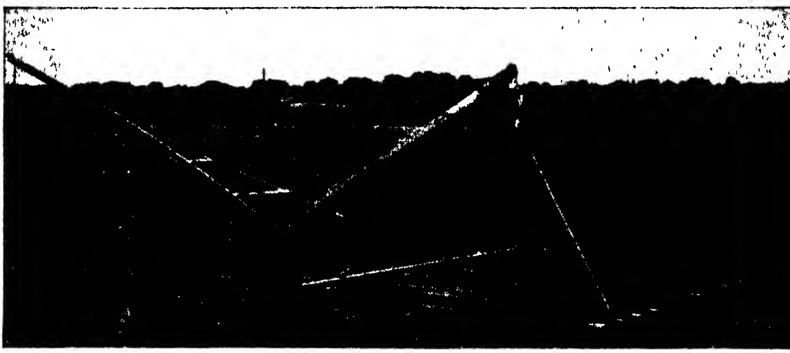

FIG. 1.—The weighing device and cart hoist used in the field studies of methods of curing hay.

After considerable preliminary work a weighing device was constructed which enabled the operator to arrive at the moisture content by weighing the same rather large amounts of hay at desired intervals without changing their normal exposure. The moisture content of the hay was determined by calculating the loss in weight from a known moisture content at the time of cutting. This device made it possible to arrive at a satisfactorily accurate approximation of the moisture content of the hay at any time during the curing process.

The device used for most of the work was a rack or frame 10 feet long and with teeth long enough to slide under and left two mower swaths of hay at a time. The teeth were of fir 1¼ inches square at the base and tapering somewhat toward the outer end. The teeth were spaced eight inches apart and bolted solidly to a 2x2-inch piece at the base making a huge comb-like frame. In lifting the rack and hay, a 1x5-inch board 10 feet long was placed under the outer end of the teeth after the rack had been slid under the hay. The two outside teeth had holes in them near the end and these were slipped over two studs in the ends of the 1x5-inch piece. Further details of the construction can be seen in Fig. 1, together with the hoist, harness, and scales.

A second weighing device of the same general type was constructed,

on a smaller scale, so that one man might operate and record the weights. It has a rigid frame and rigid teeth 5 feet long. This device is lifted by means of a strap iron bar connected solidly with the back piece of the frame and bent over the load with suitable notches in the lower side to allow for the adjustment of the scale to balance the load. A two-legged rest and a lever across the top with the scales on one end

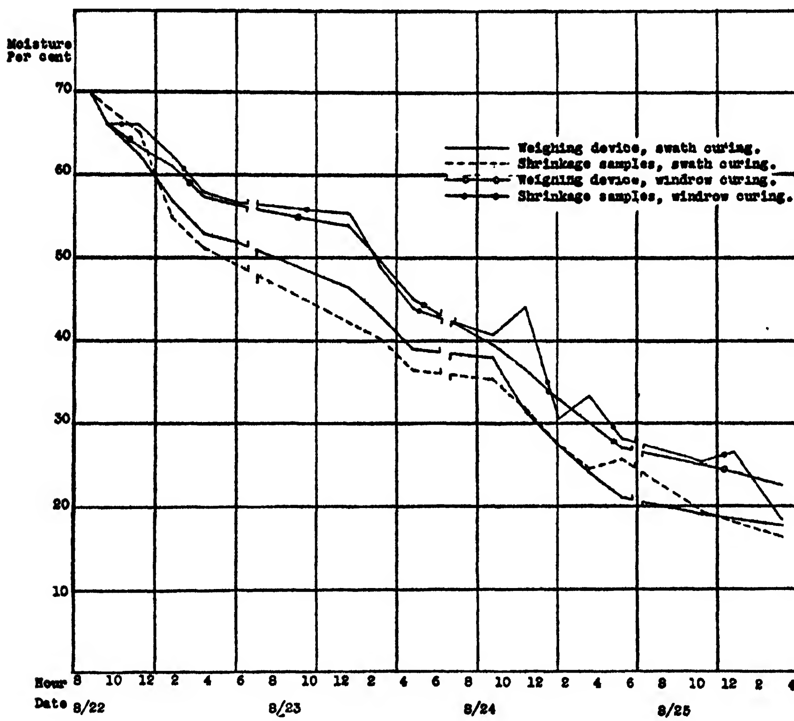

FIG. 2.—Percentage of moisture in hay curing in the field as determined at regular intervals with the weighing device in comparisons with determinations from shrinkage samples.

enable one man to lift the rack and read the weight on the scale. This device will weigh a 5-foot section of swath or windrow. Ordinary milk scales may be used for the weighing.

The use of these weighing devices involves either an actual moisture determination at the time the hay is cut or an estimate based on previous determination. The usual procedure adopted for these studies was to determine the moisture content of representative samples of the hay to be harvested for several days in sequence, prior to the day of cutting. With this information in mind, the moisture content was estimated on the day of cutting with sufficient accuracy for the early

part of the curing work, though actual determinations were also made at the time of cutting. The weights used in the experimental data presented are based on the actual moisture content.

TABLE I.—*Percentage of moisture as estimated from weighed areas compared with determinations made on oven-dried shrinkage samples, 1927.*

Hour	Swath cured		Windrow cured	
	Weighing device	Shrinkage samples	Weighing device	Shrinkage samples
		August 22		
9:00	69.70	69.70	—	—
10:00	66.29	—	66.29	66.29
12:00	62.50	65.29	63.50	66.22
2:00	57.00	55.09	61.32	62.52
4:00	53.00	51.21	57.50	57.96
6:00	52.00	52.15	56.50	56.69
		August 23		
1:00	46.50	42.24	54.00	55.47
3:00	43.00	40.14	49.50	48.95
5:00	39.00	36.42	45.00	44.05
		August 24		
10:00	38.00	35.37	39.50	40.76
12:00	31.50	31.72	36.50	44.02
2:00	27.50	27.41	33.00	31.04
4:00	24.00	24.54	29.00	33.26
6:00	21.00	25.75	27.00	28.32
		August 25		
11:00	19.00	19.37	25.00	25.23
1:00	18.50	18.55	24.00	26.56
4:00	17.60	16.31	22.50	18.25

The procedure in the use of the rack consisted of weighing three areas of hay at the start of the cutting and another set of three at the end of the cutting. The loss in weight for these areas, as shown by weighing the same areas at intervals throughout the period of curing, permitted rather accurate estimates of the degree of curing of the hay at any time and a close determination of the one-fourth, one-half, and three-fourths swath cured and cured condition. At each of these stages various methods of raking, tedding, windrow turning, cocking, and baling were used. As soon as the cutting was completed part of the hay was windrowed. Areas were weighed in these windrows, and by subsequent weighings of these areas the moisture content of the windrowed hay could be known at any time and comparisons of the rates of curing in swath, windrow, or cock could be made.

In order to facilitate the calculations of the moisture content at subsequent weighings, a chart was constructed which enabled one to read directly the moisture in the hay at any weighing, but, unless very

extended investigations are under way, the calculations can be made as each weighing is made.

The use of the rack was checked by the following procedure. Hay was cut and a portion windrowed at once. Three areas were weighed immediately in both the swath and the windrow, and three 5-pound shrinkage samples taken in each. The weighing and the taking of shrinkage samples were repeated every 2 hours during the curing of the hay. The results of this comparison are given in Table 1. A comparison of the results secured by the two methods of arriving at the moisture content of the hay is shown in the graph in Fig. 2.

A study of the data in Table 1 indicates that the weighing device gives a more uniform picture of the condition of the hay than is secured from shrinkage samples. It would appear difficult to sample half-dried hay in the windrow with accuracy. Swath-cured hay seems to cure out more evenly and successive shrinkage samples do not appear so erratic. Green hay may be sampled rather accurately by the use of shrinkage samples. Half-dried or windrow-cured hay is difficult to sample accurately, as shown by the extreme variations toward the latter part of the test.

The equipment and method described were used with very satisfactory results in an extensive comparison of methods of curing hay at the Iowa Agricultural Experiment Station. There is a possibility that with a greater knowledge of the moisture content of hay in the field at the time of cutting the use of such a device as the "one man" shrinkage sampler might be practical for farm use, giving the hay maker more accurate knowledge than he has had in the past of the time when hay is safe to store in the mow or to bale in the field. Failure to arrive at a correct decision on this point in the past has resulted in tremendous losses in hot or heating hay, farm fires, and mechanical losses due to over curing.

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THE RESISTANCE OF CERTAIN VARIETIES AND REGIONAL STRAINS OF ALFALFA TO CONTROLLED LOW TEMPERATURES[1]

F. L. TIMMONS and S. C. SALMON[2]

During the last 30 years extensive experience and a considerable number of experiments have shown marked differences in the adaptation of different varieties and strains of alfalfa. In general, Grimm and other variegated varieties and strains have proved best in northern regions, while various strains of common alfalfa or of the non-hardy group (Peruvian) are better adapted to the central and southern areas. It is reasonable to suppose that differences in adaptation are correlated with resistance to low temperature. Indeed, it is well known that adaptation in many cases is limited primarily to inability to survive severe winters and hence presumably by susceptibility to freezing temperatures. In a few cases differences in resistance to winter killing and to low temperatures have been experimentally demonstrated. In connection with other work of a similar nature at the Kansas Station, it seemed desirable to make a more extensive study of this relation in order to determine whether or to what extent resistance to low temperatures is a factor of major importance in determining the adaptation of alfalfa varieties and whether artificial freezing may be usefully employed in determining the relative resistance of varieties and strains to winterkilling.

REVIEW OF LITERATURE

The literature on the general subject of winterkilling in plants has been comprehensively reviewed by Chandler (5),[3] Newton (18), Martin (13), and others. In this paper mention will be made only of those contributions relating to alfalfa.

Lyon and Hitchcock (12), in a field test conducted at the Nebraska Agricultural Experiment Station from 1898 to 1903, observed that strains of common alfalfa from Arizona and California winterkilled completely and that common alfalfas from Utah, Colorado, and Kansas were injured more severely than those from Nebraska and Turkestan.

[1]Contribution No. 210 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication January 2, 1932.

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[3]Reference by number is to "Literature Cited," p. 654.

Brand (1) reported the results of winterhardiness studies carried on in Minnesota and North Dakota. At the Minnesota Agricultural Experiment Station, 1901 to 1908, strains of northern-grown common alfalfa winterkilled much more severely than Turkestan and Grimm, while Grimm proved to be hardier than Turkestan. At Tappen, North Dakota, in 1909, the percentages of survival were as follows: Grimm and Montana common, 90; Kansas and Nebraska common, 85; Colorado common and Russian, 60; New York common and Utah dry land alfalfa, 30; Utah irrigated, 10; and common alfalfa from Texas, Germany, France, and southern Europe, 5.

Brand and Waldron (2) reported that at Dickinson, North Dakota, in 1906 to 1909, Arabian African and South American strains killed out almost completely. European strains from 79.5 to 100%; Utah common, 90.4%; Colorado common, 86.1%; Kansas common, 84.8%; Nebraska common, 76.4%; Montana common, 65.4%; Turkestan strains, 56 to 91%; Mongolian, 39%; Turkestan selections, 9.2 to 98.7%; and Grimm from 2.8 to 7%.

Piper (20) called attention to the results from experiments that were conducted at Havre, Montana, 1916–17, and at Redfield, South Dakota in 1916 to 1920. At Havre the following percentages of winterkilling were recorded: *Medicago falcata*, 0.0; Baltic, 4.3; Grimm, 4.6; Montana common, 7.8; Canadian variegated, 13.8; Turkestan, 17.8; Liscomb, 27.8; Kansas common, 32.0; Utah non-irrigated, 42.9; Utah irrigated, 47.9; and India, 100. At Redfield, South Dakota, the percentage reduction in stands was 21.1 in Grimm, 34.9 in Baltic, 52.6 in Canadian variegated, 49.3 to 66.9 in Dakota common, 83.6 in Kansas common and 95.3 in Utah common.

Miller (14) noted differential winterkilling at Morris, Minnesota, 1916 to 1918. Grimm, Baltic, and Turkestan winterkilled 10 to 36%; northern-grown common strains 25 to 40%; and southern-grown common strains almost 100%.

Moore and Graber (15) and Graber (8) reported the results from field trials with alfalfa at the Wisconsin Agricultural Experiment Station. Common alfalfa from New Mexico, Arizona, and California proved decidedly less hardy than common strains from Kansas and states farther north, and in an extensive comparison of common alfalfas those from Kansas and Nebraska were equal in winterhardiness to those from Dakota and Montana. Grimm, Baltic, and Cossack were superior in hardiness to both southern- and northern-grown strains of common.

Experiments conducted at the Iowa Agricultural Experiment Station (9) showed Grimm and Turkestan to be the most winterhardy; Dakota, Nebraska, and Kansas commons intermediate in hardiness;

and strains from Utah, Oklahoma, and New Mexico the least hardy of those included in the comparison.

Singleton (24) found that common alfalfas from Kansas, the Dakotas, and Montana were as hardy as variegated alfalfas under irrigated conditions in Washington, whereas Hairy Peruvian winterkilled severely.

In Connecticut, Brown and Slate (3) observed that Grimm, Turkestan, Variegated, Rhode Island native, Baltic, northern-grown common, Peruvian, Kansas common, Provence, and Arabian alfalfas maintained their stands in the order named during the period 1915 to 1920.

In an experiment started at the Illinois Agricultural Experiment Station in 1926, Burlinson and Hackleman (4) noted that Grimm and Cossack showed practically no winterkilling the first season, while South Dakota No. 12, Kansas common, Colorado common, and Idaho common were intermediate and Argentine winterkilled severely.

Cox and Megee (6) and Rather and Wenner (21) concluded, on the basis of extensive field trials in Michigan, that Hardigan, Grimm, Cossack, and Ontario variegated comprised the most hardy group. Common alfalfas from northern and western states were intermediate in this respect and those from Utah and Kansas were somewhat less hardy than strains from the Dakotas, Montana, and Michigan. The non-hardy group included Hairy Peruvian, Arizona common, and strains from South America and Africa.

Kiesselbach and Anderson (10) reported the results of two rather extensive field trials with alfalfa strains carried on at the Nebraska Agricultural Experiment Station from 1922 to 1927. In one test the "stand survivals" after 6 years, expressed as a percentage, were Cossack 89, Baltic 85, Grimm 83, Turkestan 81, Nebraska common 72, Canadian variegated 69, Sand lucern 13, and Peruvian 0. Common alfalfas from 20 different sources were compared in another field test. A strain from Dawson County, Nebraska, later named Hardistan (11) maintained the best stand. Provence (F. C. I. 34886)[4] and other strains of common alfalfa from Nebraska, Kansas, South and North Dakota, Montana, Wyoming, and Colorado showed a somewhat greater loss of plants, while those from Oklahoma, New Mexico, and Texas killed out severely. The stands of Argentine, Spanish, and Italian alfalfas were practically destroyed. The loss of plants in these experiments appears to have been due chiefly to winterinjury.

In an experiment conducted by Nelson (16) at the Arkansas Agri-

[4]Accession record number, Division of Forage Crop Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

cultural Experiment Station from 1925 to 1929, the varieties ranked according to stand at the end of the period were Grimm, Baltic, Dakota common, Utah common, Argentine, Kansas common, Oklahoma common, Texas common, and Peruvian. Winterinjury was considered responsible for most of the loss of plants .

Nelson and Graber (17, page 37) exposed plants of Grimm, Turkestan, and common to artificially produced low temperatures (—4°F). Eighty-four percent of the common were killed as compared with 18% for the Grimm. Turkestan also killed less than the common.

Steinmetz (25) dug up Grimm and Kansas common plants from the field at different times during the winter and froze them under controlled conditions. Potted greenhouse plants of both varieties were also frozen. Grimm was distinctly more resistant than Kansas common. Resistance to cold increased in both varieties as winter approached and disappeared with the approach of spring, the critical period for both varieties being at the time of the spring thaw.

Steinmetz also compared Grimm and Kansas common with respect to the freezing point of the root tissue, the freezing point depression of the sap expressed from the roots, the quantity of press juice, the total solids in the sap, the viscosity of the cell sap from the roots, and the sugar, pentosan, and amino acid content of the roots. He found no definite relation between any of these factors and the relative cold resistance of the two varieties and concluded that, "as positive measures of the differences between the varieties under study, the freezing of potted plants or of roots removed from the soil has been found to be the most practicable and reliable method."

Martin (13) reached a similar conclusion with regard to wheat.

Salmon (22) compared certain alfalfa varieties in two different controlled freezing tests. Plants of Provence (F. C. I. 34886), Ladak, Grimm, Cossack, and Kansas common were grown in 12-inch clay pots in the greenhouse and frozen for 12 hours at —11°C. The estimated percentages of injury were Provence 44.3, Ladak 70, Grimm 74.4, Cossack 78.2, and Kansas common 94.7. In another test, 1-year-old plants were transplanted from the field to 4-inch pots and frozen. The estimated percentages of injury were Provence 35.2, Grimm 37.4, Ladak 46.2, 1-year-old Kansas common 50.2, and 2-year-old Kansas common 45.1.

Peltier and Tysdal (19) froze 6 weeks old greenhouse-grown plants in controlled freezing chambers. The ratios of survival compared with a standard strain of Turkestan were Provence (F. C. I. 34886) 115, Hardistan 115, Ladak 105, Grimm 87, Nebraska common 72, and Arizona common 26. Several strains of Turkestan showed varying degrees of survival.

MATERIALS AND METHODS

The experimental work reported here was conducted at two different seasons, with different sets of plant material, and with slightly different methods. The first experiments were conducted in the fall of 1929 with five varieties which had been seeded on August 23, 1929, in square rod plats on the Kansas Agricultural Experiment Station Agronomy Farm, Manhattan, Kansas. These varieties were Provence (F. C. I. 34886), Ladak (from Redfield, South Dakota), certified Grimm (from Idaho), Kansas common, and Utah common.

Clumps of from 6 to 10 plants were transplanted from the field into 4-inch clay pots with a small garden trowel, one clump being placed in each pot without seriously disturbing the soil about the roots. The pots were then transferred directly to the refrigerator or held outside of the greenhouse until frozen. They were frozen in the carbon dioxide automatic temperature controlled refrigerator described by Sellschop and Salmon (23). Each freezing lot consisted of 15 pots of each variety distributed throughout the freezing chamber. Transplanted but unfrozen plants of each variety of each freezing lot were retained in the greenhouse as checks. In most cases a portion of the plants of each variety of each freezing lot was removed from the refrigerator at the end of 12, 15, and 18 hours. In two cases the period of freezing was 48 hours. Since the relative degree of injury for each variety seemed to be approximately the same regardless of the period of freezing, no distinction is made with respect to this factor in the presentation of the data. The different lots were subjected to various freezing temperatures ranging from about —11° to —28°C depending upon the degree of hardening of the plants. Those temperatures were chosen which previous experience had indicated would produce a moderate injury in the more resistant varieties. After each lot had been frozen it was placed in the greenhouse to thaw and was then maintained under optimum conditions of moisture and temperature for several weeks for observations on recovery.

The injury was estimated for each pot of each variety at various intervals, ranging from 4 to 15 days after freezing for the first estimates to from 2 to 11 weeks after freezing for the final estimates. The estimates were based on the appearance of the above-ground parts as compared with the unfrozen checks of the same lot and variety.

Immediately after making the final estimate of injury the plants were removed from the soil and the number of dead and surviving plants recorded. The surviving plants were then examined for root injury and the number of those injured and with uninjured roots

were recorded. Those with roots frozen off so that the plants were subsisting entirely by new rootlets from the crown were recorded as severely injured.

The second set of experiments was conducted in the fall and winter of 1930–31 and comprised 11 regional strains of alfalfa, seed of which was secured from H. L. Westover of the U. S. Dept. of Agriculture; Kansas common, seed of which was produced in northwestern Kansas; and three named varieties, Hardistan, Ladak, and Grimm.

The plants were transplanted to 4-inch clay pots for freezing as in the previous year except that the tap roots were cut off at a uniform length of 4 inches from the crown and three plants were placed in each pot. Care was taken to place each plant about 1 inch from the side of the pot and so to place the plants that the soil in the pot came to the same point on the crown that it had in the field. As in previous seasons all pots were heavily watered a short time before freezing. Each freezing lot consisted of five pots of each variety distributed throughout the freezing chamber. One pot of each variety of each lot was retained unfrozen as a check. The plants were subjected to temperatures varying from —10.5° to —13°C and the time of exposure varied from 11 to 13 hours. Estimates of injury and the determinations of living, injured, and dead plants were made as in the preceding season. In addition, an attempt was made to measure the size of the roots of each variety to determine whether differences in varieties were influenced by differences in size such as might result from unequal stands.

EXPERIMENTAL RESULTS

EXPERIMENTS IN 1929–30

Seven lots, each consisting of 15 pots of each variety, were frozen in the fall of 1929, beginning on November 2 and continuing until December 19. The date of freezing, the temperature of freezing, the percentage of plants killed in each lot, and the average percentage killed of each variety for all lots are given in Table 1. The probable error of the mean was determined from the probable error of the experiment calculated by the method suggested by Student (25) and discussed by Goulden (7).

It is apparent that Kansas common and Utah common were killed to practically the same extent, Grimm considerably less, and Provence (F. C. I. 34886) least of all. Ladak was intermediate between Grimm and Provence. Peltier and Tysdal (18) have also found this strain of Provence to be more resistant to low temperature than Grimm and Ladak. It is of interest to note that with the possible exception of

Ladak and Provence the varieties retained approximately the same position relative to each other whether frozen early in the fall before they had had an opportunity to harden, as was the case in the first three lots, or later in the fall after having been subjected to freezing temperatures, as were the last four lots. The minimum daily temperatures for the last week in October and the first 2 weeks in November ranged from slightly below to above 32°F, while the maximum daily temperatures were below 50°F on only 4 days. On the other hand the four lots frozen last were subjected to rather severe temperatures, reaching as low as —1°F on November 22.

TABLE 1.—*The relative resistance of varieties of alfalfa to low temperature as indicated by percentage of plants killed.*

Variety	Date and temperature of freezing							
	Nov. 2, —11° C	Nov. 10, —11° C	Nov. 16, —11° C	Dec. 7, —21° C	Dec. 8, —21° C	Dec. 19, —28° C	Dec. 19, —28° C	Mean
Provence F.C.I. 34886	47.1	30.6	24.6	38.2	9.6	75.9	33.3	37.0
Ladak	81.4	55.0	66.6	68.3	16.4	46.7	25.8	51.5
Grimm	80.2	97.1	82.0	84.0	29.7	78.3	61.8	73.3
Kansas common	97.9	94.3	96.5	99.0	87.1	100.0	87.1	94.5
Utah common	97.3	99.2	98.1	98.8	86.6	95.1	92.8	95.4

P.E. of a variety in a single lot of the experiment = 9.14%.
P.E. of the mean of a variety = 3.46%.

It is of some interest to know whether freezing injury to alfalfa plants can be estimated with reasonable accuracy, and accordingly the average injury for each variety was compared with the percentage of plants killed and the percentage of dead plants plus those with injured roots. Pertinent data are given in Table 2.

TABLE 2.—*Comparing different methods for determining relative injury to alfalfa from low temperatures.*

Variety	Total No. of plants frozen	Killed, %	Killed and injured, %	Estimated injury, %
Provence (F. C. I. 34886)	340	37.0	57.6	51.9
Ladak	799	51.5	63.5	51.0
Grimm	757	73.3	79.8	70.2
Kansas common	718	94.5	96.6	95.0
Utah common	897	95.4	96.7	91.8
Probable error of the mean		3.46	3.50	4.34

On the whole, the estimated injury agreed rather closely with the other two measures of cold resistance. The variation, however, was greater, as shown by the higher probable error. Giving due weight to chance fluctuation it will be seen that the varieties would be ranked

in the same order regardless of which measure is used, with the exception of Provence and Ladak. As measured by the estimated injury, Provence was no more hardy than Ladak, whereas by either of the other two measures Provence would be considered slightly superior to Ladak.

EXPERIMENTS IN 1930–31

Uniformly good stands were obtained for the 15 varieties and regional strains planted in April 1930 and a vigorous growth was secured during the summer. The plants attained a height of 10 to 16 inches and bloomed profusely in the early fall. The top growth was left on until after the first heavy frost. Nine lots of each variety were transplanted and frozen in November and three lots in January and February. Each lot consisted of five pots of each variety, making a total of 60 pots or 180 plants of each variety frozen.

Unusually mild temperatures prevailed throughout the winter and it is probable that in none of the lots were the plants as thoroughly hardened as is usually the case. The minimum daily temperatures during the last week in October and the first 3 weeks in November, when the first nine lots were transplanted and frozen, were materially below freezing only three times, *viz.*, 17°F, 19°F, and 23°F on October 31, and November 6 and 7, respectively. During this time the maximum daily temperature was below 50°F only once and exceeded 65°F on 18 different days. Later in the year the minimum daily temperatures ranged mostly below 32°F and were as low as 3°F. The plants frozen on February 7 had been transplanted January 3 and had remained outside of the greenhouse in 4-inch pots from January 3 to February 7, except on January 14 when they were put in the greenhouse for 1 day to protect them from a minimum temperature of 3°F. All other lots were frozen soon after transplanting.

The date and temperature of freezing, the percentage of plants killed for each lot, and the averages for all lots are given in Table 3.

The probable error of the mean calculated by the Student-Fisher method was found to be 2.63%. Hardistan, a strain discovered by the Nebraska Experiment Station (11), was distinctly the most cold-resistant strain in the test. Ladak and Grimm survived to about the same extent, being considerably more resistant to cold than any of the common alfalfas. It is of interest to note that this agrees with Peltier and Tysdal (19) who found Hardistan more resistant to low temperature than any other variety tested, including Ladak and Grimm, excepting only Provence (F. C. I. 34886) which it equaled. The strains of common alfalfa grouped themselves into two broad classes with respect to survival, *viz.*, a non-hardy group consisting of strains from

TABLE 3.—*Relative injury of varieties and regional strains of alfalfa artificially frozen, 1930–31, as indicated by percentage of plants killed.*

Variety or strain	Date and temperature of freezing												
	Nov. 13, —13° C	Nov. 2, —11° C	Nov. 3, —11° C	Nov. 20, —12° C	Nov. 11, —12° C	Nov. 11, —13° C	Nov. 12, —13° C	Nov. 13, —13° C	Nov. 22, —12° C	Feb. 7, —13° C	Feb. 7, —13° C	Mar. 1, —10.5° C	Mean
Hardistan (Nebr.)	53	19	7	27	13	25	6	45	27	55	23	25	27.1
Ladak (S. Dak.)	82	59	25	44	7	35	47	64	50	40	29	41	43.6
Grimm (Utah)	72	21	47	58	43	69	20	75	38	22	40	29	44.5
Nebr. Common (F. C. I. 15897)	92	56	53	67	36	64	47	94	66	61	87	37	63.3
Colo. Common (F. C. I. 14482)	75	53	46	71	50	65	74	100	80	42	66	41	63.6
Dakota Common (F. C. I. 16081)	88	75	60	87	53	52	29	100	93	47	75	61	68.3
Utah common (F. C. I. 15986) Uinta Basin, Utah	100	43	100	87	29	50	88	87	73	47	56	83	70.3
Kan. common	93	67	50	80	27	69	73	100	93	65	82	100	74.9
Okla. common (F. C. I. 15902)	90	73	80	80	67	80	56	93	73	75	71	83	76.8
Idaho common (F. C. I. 17397)	85	87	87	93	46	44	65	100	100	78	74	64	76.9
Utah common (F. C. I. 15995) Millard Co., Utah	90	87	94	86	43	62	100	100	69	40	88	67	77.2
N. M. common (F. C. I. 14470) Roswell, N. M.	100	80	80	93	53	67	100	100	87	88	95	94	86.4
N. M. common (F. C. I. 15877) Loving, N. M.	100	80	87	100	80	86	100	100	93	94	100	83	91.9
Ariz. common (F. C. I. 15837) Yuma, Ariz.	100	100	93	100	77	86	100	100	100	88	95	100	94.9
Calif. common (F. C. I. 15889) Palo Verde Valley, Cal.	100	100	100	100	92	100	100	100	100	94	100	100	98.8

P.E. of a variety in a single lot of the experiment = 9.11%.
P.E. of the mean of a variety = 2.63%.

California, Arizona, and New Mexico which survived considerably less than those of the intermediate group which included strains from Nebraska, Colorado, the Dakotas, Utah, Kansas, Idaho, and Oklahoma. The differences within this latter group are rather small; however, Nebraska common, Dakota common, and Colorado common appear to be significantly more hardy than the strains from Utah, Kansas, Idaho, and Oklahoma. The strains from Utah, Kansas, Idaho, and Oklahoma were killed to about the same extent.

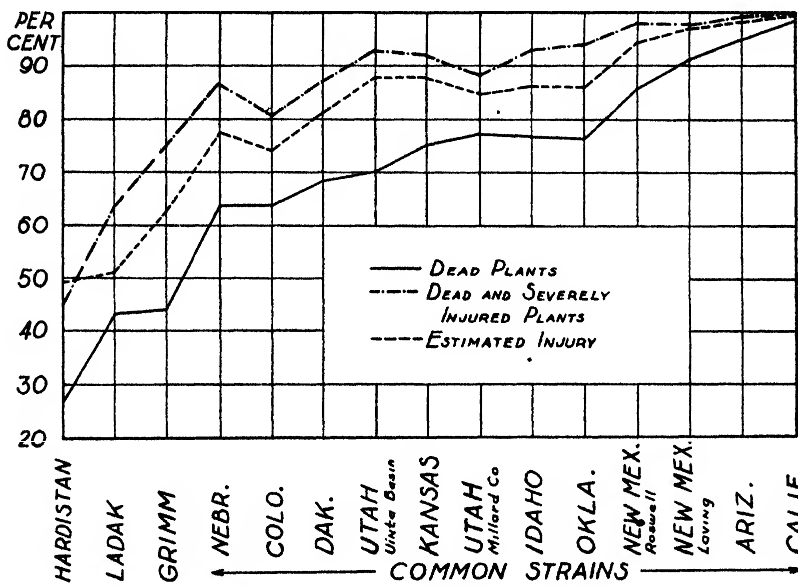

FIG. 1.—Comparison of three different indexes to the cold resistance of alfalfa varieties.

As in the preceding season, an attempt was made to estimate the degree of injury from the appearance of the portion of the plants above ground. The average of these estimates for all lots is given in Table 4, together with the average percentage of plants killed and with the average percentage of plants killed and severely injured combined. The same information is shown graphically in Fig. 1.

In general, the three different measures of resistance agree very well as shown further by the fact that the correlation coefficient for estimated injury and dead plants is $.970 \pm .010$ and between estimated injury and dead and severely injured plants is $.956 \pm .015$.

It seems therefore that the degree of injury can be estimated with a reasonable degree of accuracy.

There appears to be one exception to this, namely, with respect to Hardistan. This variety survived considerably better than would be expected on the basis of estimated injury. The same was true for Provence (F. C. I. 34886) frozen in 1929. Both of these varieties appear to be unusually resistant to low temperatures and they appeared to renew their top growth less promptly after freezing than the others. This may possibly account for the failure of the observer to estimate accurately the relative injury sustained by them.

TABLE 4.—*Comparing plants killed, plants killed and severely injured, and estimated injury as a measure of resistance to low temperature of alfalfa varieties.*

Variety	Dead plants %	Plants dead and severely injured %	Estimated injury %
Hardistan (Nebraska)	27.1	44.7	49.1
Ladak (S. Dakota)	43.6	63.8	50.3
Grimm (Utah)	44.5	74.9	62.5
Nebr. common (F. C. I. 15897)	63.3	86.9	78.8
Colo. common (F. C. I. 14482) Great Divide, Colo	63.6	80.4	74.0
Dakota common (F. C. I. 16081)	68.3	87.6	81.5
Utah common (F. C I. 15986) Uinta Basin, Utah	70.3	92.7	88.1
Kan. common	74.9	92.2	88.1
Idaho common (F. C I. 17397)	76.9	92.9	86.3
Okla. common (F. C. I. 15902)	76.8	94.1	85.9
Utah common (F. C. I. 15995) Millard Co., Utah	77.2	88.8	84.7
N. M. common (F. C. I. 14470) Roswell, N. Mex.	86.4	98.3	94.6
N. M. common (F. C. I. 15877) Loving, N. M.	91.9	97.9	97.5
Ariz. common (F. C. I. 15827) Yuma, Ariz.	94.9	99.4	98.6
Calif. common (F. C. I. 15889)	98 8	100.0	99.1
Probable error of the mean	2.63	1.91	2.17

INFLUENCE OF SIZE OF ROOTS ON COLD RESISTANCE

The root diameters of all plants frozen in 1930–31 were measured at the time the plants were examined for root injury. The size of roots in all varieties ranged from 4 to 11 mm. in diameter and the average root diameters for the different varieties or strains ranged from slightly below to slightly above 6 mm. No consistent or definite influence of the size of roots on cold resistance was noted in any variety. Plants with root diameters ranging from the smallest to the largest were found in the dead, injured, and uninjured groups within nearly every variety. In some of the varieties the roots of dead and injured plants averaged slightly smaller than those of slightly injured or uninjured plants; in other varieties the reverse was true. It is

apparent then that the size of the roots was not an important factor in the relative cold resistance of the different varieties and strains in this experiment.

COLD RESISTANCE AND DISTRIBUTION OF VARIETIES AND STRAINS

A close relation between the cold resistance of the commercially important varieties and strains and the severity of the winters in the regions where they have become adapted is apparent. Very little is known about the history or the adaptation of Provence (F. C. I. 34886) and Hardistan, the most resistant varieties in these experiments, hence they cannot be considered in this connection. Ladak and Grimm are well known to be especially adapted to northern states characterized by severe winters, whereas strains of common alfalfa from Arizona, New Mexico, and California are even more definitely limited to southern areas.

The Dakota common which came from the Black Hills section of South Dakota is perhaps less resistant to low temperatures in comparison with Nebraska common and Colorado common than its origin would suggest. However, the winters in and near the Black Hills are less severe than in other portions of South Dakota. Also, the Great Divide region of Colorado from which the Colorado common here used was obtained is an area of more than 6,000 feet elevation and is characterized by very severe winters, which possibly accounts for the relatively high resistance of this strain to cold. The experiments do not show any consistent or marked differences between the various strains from Idaho, Kansas, Utah, and Oklahoma. Thus, the difference between the two Utah strains is greater than that between any other two strains of the group. This is not entirely in accord with the relative survival of strains from these regions under field conditions. However, large differences would not be expected and no doubt the differences between lots secured within the boundaries of each state would vary as much as those reported here. It is probable that the establishment of a relation between resistance to low temperature and distribution of strains from these states would require more extensive experiments than reported here and especially more exact knowledge as to the source of seed and its previous history than was available in this case.

SUMMARY

1. Several hundred plants of each of several varieties and strains of alfalfa were grown in the field, transplanted, and frozen under controlled conditions in the fall and early winter of 1929–30 and 1930–31.

2. Provence (F. C. I. 34886) and Hardistan proved to be more resistant than any other variety or strain tested. Grimm and Ladak were second. A third group consisted of Dakota common, Nebraska common, and Colorado common. Kansas common, Utah common, Idaho common, and Oklahoma common made up the fourth group and a fifth group consisting of strains from Arizona, New Mexico, and California was the least resistant of any.

3. In general, the resistance of the various strains to low temperatures was found to correlate very well with the severity of the winters of the regions to which the various strains had become adapted.

4. It was found possible to estimate the relative injury to the different varieties very satisfactorily in most cases. The correlation between estimated injury and dead plants was found to be .970 ± .010 and between estimated injury and dead and severely injured plants, .956 ± .015. Hardistan and Provence (F. C. I. 34886) survived somewhat better than would have been expected on the basis of estimated injury.

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THE ROLE OF ORGANIC MATTER IN THE CLASSIFICATION OF FOREST SOILS[1]

M. F. MORGAN and H. A. LUNT[2]

In the forest the deposit of organic substances upon the surface of the soil in the form of leaves, twigs, bark and other vegetative residues is perhaps the most conspicuous feature of the ground. This material in a well-stocked forest amounts to from 3,000 to 5,000 pounds per acre per year on the basis of measurements reported by Henry (5)[3] and others. Our own measurements in 27-year-old pine plantations give figures ranging from 2,000 to 3,000 pounds. This does not include the under ground residues derived from roots, fungal mycelia, insects, earthworms, and microbial cells to which no numerical values can be assigned. The transformation of this organic

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[3]Reference by number is to "Literature Cited," page 662.

matter is a process which vitally affects the nutrition of the tree as well as the temperature, aeration, and moisture conditions of the soil in direct relation to plant growth. The decomposition products of forest organic matter exert a predominant effect upon the character of soil profile development.

QUALITIES PECULIAR TO FOREST SOIL ORGANIC MATTER

CARBON-NITROGEN RATIO

One of the most significant characteristics of the organic matter in Northeastern forest soil profiles is its wide carbon-nitrogen ratio. This was pointed out by the senior author in previous papers before this Society (10, 11). The following values are characteristic:

	Podsol type	Mull type
"F"	1:29	1:33
"H"	1:27	—
A_1	—	1:25
A_2	1:24	1:24
A_3	—	1:20
B_1	1:28	1:18
B_2	1:26	1:17
C	1:20	1:15

There are wide variations from these amounts for any individual horizon of a given profile, but in no case, except in forest plantations on old cultivated fields, have we encountered ratios which are at all like the commonly accepted values of 1:10 or 1:12.

Dunnewald's (2) figures for the Big Horn Mountains region show a similarly wide carbon-nitrogen ratio for forest soils, but his figures are quite variable and are based upon carbon values assumed from loss on ignition

Alway and Harmer (1) in studies of the nitrogen carbon-ratio of the forest floor and the underlying 6 inches of soil in three Minnesota forests found ratios of only 1:19, 1:18.4, and 1:24.1 for the forest floor and 1:13.1, 1:12.3 and 1:13.5 for the underlying soil.

CHEMICAL NATURE

The chemical nature of the organic matter of soils is partially revealed by the methods of organic analyses employed by Waksman and his co-workers. Up to the present time this method has been little used in soil profile studies. However, Waksman and Stevens (14) give figures for the A and B horizons of a tschernosem soil from Fargo, North Dakota, while Watson (15) has analyzed a white pine forest soil profile from Keene, New Hampshire. In order to reduce

these to a comparable basis, the results have been recalculated on the basis of percentages of the amounts of organic substances actually recovered and are recorded in Table 1.

TABLE 1.—*Fractional organic analyses of soil profiles.*

Horizon	Ether-soluble %	Water-soluble %	Alcohol-soluble %	Hemi-cellulose %	Cellu-lose %	Lignin complex %	Protein %
			Fargo, N. D., Prairie Soil				
A.........	2.9	2.7	1.1	2.0	6.6	31.8	32.9
B.........	2.5	2.6	1.1	3.2	5.7	53.4	31.5
			Keene, N. H., Forest Soil				
Fresh litter	7.7	6.2	7.0	15.7	15.9	40.5	7.0
F.........	4.6	5.6	5.0	13.9	9.1	51.0	11.7
H.........	4.4	4.6	5.7	11.8	5.8	55.3	12.4
A_1........	5.0	5.1	4.9	10.8	2.8	55.0	16.4
A_2........	4.2	5.4	2.2	8.6	1.2	56.9	21.5
B.........	1.3	3.3	6.5	4.9	1.4	41.6	46.8

The organic horizons, as would be expected, show relatively high contents of cellulose and hemi-cellulose. The organic matter of the A and B horizons of the forest soil contains much more water-soluble and alcohol-soluble material and less cellulose than the corresponding horizons of the prairie soil. The protein content is much higher in the prairie soils, except in the probably abnormal B horizon of this particular forest soil. The nitrogen-carbon ratios of the B horizons which we have studied would not substantiate any such high protein content.

PROPERTIES OF THE FOREST SOIL PROFILE INFLUENCED DIRECTLY BY THE ORGANIC MATTER

REACTION

The organic matter in forest soils is chiefly derived from leaves and needles which, when freshly fallen, are capable of producing a definitely acid reaction when moistened with water. Hesselmann (6) has found this to vary over a wide range to as low as 3.7 pH in case of the leaves of mountain cranberry, there being a general correlation between pH values and the calcium which is extracted with 10% ammonium chloride. The coniferous needles and the leaves of dwarf shrubs as a group were found to be more acid than the leaves of hardwoods and herbaceous plants.

Under conditions of rapid decomposition of the litter, with the incorporation of the humus residues into the upper mineral soil, as in active mull formation, there appears to be no consistent acidifying

effect upon the soil thus formed. Often such soils are less acid in the A_1 horizon than in the middle portion of the profile.

It is a different story with the very slowly and incompletely decomposed layers of forest organic residues, to which the general term "raw humus" is often applied, and which are now frequently designated as the "F" and "H" horizons of duff type. Under normal conditions the acidity of these layers is materially greater than that of the fresh litter from which they are formed, especially in the "H" layer.

Exceedingly low pH values, ranging well below 3.5 pH, are not uncommon. Romell and Heiberg (12) report 20 samples between 2.6 and 3.0 pH. It is impossible to picture any simple organic acid that is capable of producing this degree of dissociation. The authors have encountered no samples below 3.0 pH.

This high organic acidity is undoubtedly an important factor in the ability of such unincorporated humus layers to produce intensive leaching of bases and sesquioxides from the uppermost mineral soil horizon. Perhaps we have ceased to believe in hypothetical crenic and apocrenic acids, but we cannot gainsay the action of forest organic matter of strongly acid reaction in the podsolizing process. As Joffe (9) has recently suggested in an excellent review of the subject, when the nature of organic colloids in forest humus in their relation to anion and cation exchange reactions is fully revealed, we may understand the process that produces an A_2 horizon with less than 2% and B horizons with as much as 15% of organic matter.

The reaction of the A_2 horizon of a well-developed podsol is usually practically the same as that of the H layer, while the B horizons become progressively less acid with depth.

COLOR

In prairie and meadow soils a high organic content is visibly indicated by the black color of the soil. In forested regions black or gray black colors in well-drained cultivated soils are rarely encountered, even though the soils may contain as much organic matter as a fertile "corn-belt" soil of a definitely black appearance. The so-called "coffee brown" B_1 horizons of many of our well-developed forest podsol profiles contain 12% or more of organic matter, yet they are of a definitely brown color. The organic matter of the B_2 (or "rust brown" layer) is frequently as high, if not higher, in organic matter, yet a reddish yellow brown coloration is the rule. In order to bring out some of these differences, we present in Table 2 a few color analyses of the 100-mesh material.

TABLE 2.—*Color analyses of tschernosem and forest soil horizons in relation to organic content.*

Horizon	Organic matter %	Color analyses			
		Black %	White %	Red %	Yellow %
		Tschernosem			
A_1	11.46	86	6	4	4
A_2	3.91	80	8	6	5
B	1.59	74	11	10	5
		Forest Podsol			
H	88.20	76	3	7	14
A_2	1.47	63	25	4	8
B_1	14.27	74	4	11	11
B_2	14.36	67	5	15	13
		Forest Mull			
A	19.31	84	4	6	6
B	4.15	74	10	10	6
C_1	1.62	70	14	11	5

VOLUME WEIGHT

The organic content of forest soil horizons has a particularly pronounced effect upon their volume weight to a much greater degree than can be ascribed to the effect of the organic matter in reducing the actual specific gravity of the soil material. The figures given in Table 3 are typical.

TABLE 3.—*Volume weights of forest soils.*

Tschernosem soil material		Forest soil material	
Loss on ignition* %	Volume weight	Loss on ignition %	Volume weight
4.17	1.358	3.9	1.297
5.96	1.318	5.5	1.116
7.08	1.248	6.6	1.047
10.94	1.143	11.5	0.890
13.24	1.135	14.4	0.837

*On soils containing no carbonates.

Harland and Smith's (4) values for the volume weight of Illinois surface soils of silt loam texture show volume weights ranging from 1.204 to 1.619. They do not present figures for the organic contents of these soils, but the soil series names indicate that such a correlation exists.

VERTICAL DISTRIBUTION OF ORGANIC MATTER

The superficial layers of organic material on the forest floor, particularly in northern forests, have been extensively studied. Romell

and Heiberg (12) have presented an excellent review of the literature pertaining to humus layers and have proposed a workable classification based upon field observations of the physical properties which are characteristic of the organic residues in the F, H, and A_1 horizons. However, the distribution of organic matter through the balance of the profile is at least of equal significance. This is true both in faintly podsolic or "braunerde" soils which show only a small fraction of their organic content in the superficial forest floor and in the well-developed humus-podsol and humus-iron podsol types which characterize many of our northern American forests. The vertical distributions of organic matter in a few such horizons are presented in Table 4.

TABLE 4.—*Vertical distribution of organic matter.*

Thick podsol in virgin forest near Waterville, N. H.

Horizon	F	H_1	H_2	A_2	B_1	B_2	C_1
Thickness, inches ..	1	3	1	4	1	8	6
Weight of soil per acre-inch, pounds	20,000	40,000	40,000	294,465	203,860	249,163	339,768
Organic carbon, % .	50.47	49.00	45.02	0.853	8.28	8.336	1.833
Organic matter per acre, pounds ...	18,674	105,840	32,414	17,404	29,099	286,599	64,422

Total organic matter in entire profile 554,450 pounds per acre

Thin podsol in forest near Union, Conn.

Horizon	F	H	A_2	B_1	B_2	C_1
Thickness, inches	0.5	2	1	1.5	7	8
Weight of soil per acre-inch, pounds	15,000	40,000	260,488	215,186	226,512	339,768
Organic carbon, %	44.50	42.20	2.62	5.02	5.33	0.40
Organic matter per acre, lbs.	6,173	60,768	11,766	27,934	145,697	18,743

Total organic matter in profile 271,081 pounds per acre

Rich crumb mull in forest near Bethlehem, N. H.

Horizon	Litter	A	B	C_1
Thickness, inches	0.75	7	10	6
Weight of soil per acre-inch, pounds.	20,000	249,163	317,116	339,768
Organic carbon, %	48.2	11.2	2.41	0.94
Organic matter per acre, pounds.	13,664	336,773	131,757	33,037

Total organic matter in profile 515,231 pounds per acre

Crumb mull in forest near Groton, Conn.

Horizon	Litter	A_1	A_2	B_1	B_2	C_1
Thickness, inches.	0.25	1	6	6	6	4
Weight of soil per acre inch, pounds.	16,000	181,210	249,163	294,465	317,117	339,768
Organic carbon, %.	51.0	9.41	4.17	1.787	0.496	0.476
Organic matter, per acre, lbs.	3,774	29,397	107,474	54,430	16,400	11,152

Total organic matter in profile 222,627 pounds per acre

TOTAL QUANTITY OF ORGANIC MATTER

The deep black color of prairie soils has led to the belief that they contain more organic matter than do forest soils. Glinka (3) presented analyses of a certain prairie soil in the tschernosem zone which may be calculated to contain approximately 1,000,000 pounds per acre of organic matter to a depth of 40 inches, or about 40,000 pounds of nitrogen.

However, computations from data pertaining to Iowa "Carrington silt loam" (13), North Dakota "Barnes silt loam" (7), and an "ordinary clayey Tschernosem" (exhibited on the Russian Tour in 1930) all fail to show such high amounts of organic matter in prairie soils. The data show the following quantities per acre to a depth of 40 inches:

	Organic matter, pounds	Nitrogen, pounds
Carrington silt loam	251,045	13,720
Barnes silt loam	314,762	15,903
Ordinary clayey tschernosem	499,725	27,740

On the other hand, four representative forest soil profiles from New England to a depth of 24 inches contained the following:

	Organic matter, pounds	Nitrogen, pounds
Virgin podsol, White Mountains	554,450	11,305
Hardwood mull, Bethlehem, N. H.	520,736	17,628
Connecticut podsol	278,109	5,417
Connecticut mull	224,384	5,717

These results show that the organic matter of forest soils may be of the same order of magnitude as prairie soils. However, on the basis of Jenny's (8) studies concerning the effect of climate upon the organic content of soils, it is reasonable to assume that the analyses based on the White Mountains forest soil represent extreme conditions with respect to organic matter accumulations in forest soils over the major portion of the United States.

It must be borne in mind that Jenny's (8) conclusions with reference to the higher organic content of prairie soils are based chiefly upon plow-depth samples of cultivated soils. These fail to present the true picture, both with respect to total organic accumulation in the entire profile and the carbon-nitrogen ratio.

The chief differences then between the organic matter of forest and prairie soils are to be found in its character and vertical distribu-

tion. Dunnewald (2) has shown that these differences may be readily detected in soils of the same region and practically adjacent to each other, as in the Big Horn Mountains of Wyoming.

SUMMARY

The total quantity of organic matter in the forest soil profile is not greatly dissimilar to that in the much darker colored prairie soils profile. The chief differences lie in its character and vertical distribution. In this capacity organic matter has a most important and controlling influence upon the morphology of the forest soil profile.

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NOTE

TRANSFERRING SMUT IMMUNITY TO HARD RED SPRING WHEAT

In 1927, Komar, a rust-resistant, hard, red spring wheat, was crossed with Hussar, a hard, red winter wheat immune to certain physiologic forms of bunt. The F_1 plants, unsmutted, were grown in the greenhouse the following winter. The F_2 and succeeding generations were grown in the nursery at Dickinson, N. Dak., from 1928 to 1931, using smut-inoculated seed. Varying, but fairly good conditions for smut infection prevailed. The inoculum was a mixture of nine collections of smut used in a uniform smut nursery in 1928 and 1929, being mostly *Tilletia levis* with a small proportion of *T. tritici*.

The plants having a winter habit usually failed to produce seed when spring sown and were largely eliminated in the second generation. Each year seed was saved only from spring habit plants having no smut, no effort being made to save a random population or to make a genetic study. About 4% of the plants developed smut in F_2, 5% in F_3, none in F_4 and only 1 plant in 3,241 showed smut in the F_5 generation. In the same tests Komar contained from 24 to 42% of smut each year and the Hope variety from 1 to 3%. The plants in certain families were entirely free from bunt in the F_3, F_4, and F_5 generations. Seed of 19 F_5 plants from these smut-free families was inoculated and grown in a greenhouse under controlled conditions favorable for bunt infection. No smut was found in the 19 hybrids, although every head of Komar was smutty. It was not possible to include the Hussar parent in a comparable smut test with the hybrids as winter wheat often fails to head when sown at the usual time for spring seeding.

The immunity of Hussar winter wheat to certain forms of smut thus has apparently been transferred to hard red spring wheat by crossing. So far as the writer is aware, this is the first instance of immunity to numerous collections of smut in a hard red spring wheat. Probably, however, these hybrids will prove susceptible to the physiologic forms of bunt which attack Hussar.

The writer wishes to acknowledge the assistance of V. H. Florell for making the crosses at Davis, Calif., and of J. A. Clark for growing the F_1 hybrids and testing some lines for smut reaction in the greenhouse at Arlington Farm, Arlington, Va.—RALPH W. SMITH, *Bureau of Plant Industry, U. S. Dept. of Agriculture.*

BOOK REVIEWS

DIE LEHRE VOM ADSORPTIONSVERMÖGEN DER BÖDEN (THE SCIENCE PERTAINING TO THE ADSPORTION PROPERTIES OF SOILS)

By K. K. Gedroiz. Translated into German from the original Russian by H. Kuron. Dresden-Blasewitz: T. Steinkopff. Ed. 2. 136 pages. 1931. Unbound, RM 5.

This is the second edition of this valuable work by a pioneer in the field of the adsorption properties of soils. The first edition appeared in 1922 and had a similar purpose in view as has the present one, namely, to present the views of the author on this very important subject largely from the standpoint of his own researches. It is written more for the college student and beginner in this branch of soil study than for the research worker who may be more interested in the theories underlying soil adsorption.

The subjects dealt with include the various types of adsorption properties of soils, such as mechanical and physical adsorption, adsorption under reduced surface tension, and under variations in the dispersed phase. Coagulative properties of electrolytes and the reactions between soils and various salts are discussed. Chapters also deal with the chemical and biological adsorption properties of soils.

Many important points are illustrated by data from the author's own experiments and in general the publication gives a concrete and comprehensive view of the field of soil adsorption. (R. C. C.)

ARBEITEN ÜBER KALIDUNGUNG (RESEARCH ON POTASH MANURING)

By O. Eckstein, A. Jacob, and F. Alten. Berlin: Verlagagesellschaft fur Ackerbau M B H. 237 pages, illus. 1931.

This book deals with the research work of the above-named experiment station which was established in 1929 for potash research. The first 63 pages describe and illustrate very admirably the buildings, laboratories, and physical equipment of the station. Some 20 pages are then given over to the character and lay-out of the soils of the station farm. The remainder of the book deals with the research work of the station under the following headings:

Laboratory research on soils, with special regard to tropical soils; comparative tests of various methods of determining available soil potash; the potash content of plants and its form of combination; effects of potash on the quality of crop; potash salts as plant protective agents; physiological reactions of potash salts; fertilizer effects of anions; tests with various potash and magnesia-containing fertilizers; tests with various combinations of commercial fertilizers; and research on the significance of potash in the animal organism.

Many tables of original data are presented and the work in general represents a high quality of research. It is well worth the study of anyone interested in soils and fertilizers and especially of the student interested primarily in potassium fertilization. (R. C. C.)

MAISSORTEN IN UNGARN (VARIETIES OF CORN IN HUNGARY)

By J. Surányi and E. Villax. Magyarovar, Hungary: 64 pages and 14 plates (40 figures, 32 in color). Pages 1–38 in German, 41–64 in English. $2.

The brief descriptions and illustrations, more particularly the latter, afford a convenient reference to the character of the different kinds of corn grown in Hungary, that should be of interest to many American agronomists working with corn. A list of seedsmen from whom the different varieties can be obtained also is included. (F. D. R.)

AGRONOMIC AFFAIRS

MEETING OF THE NORTHEASTERN SECTION

The Northeastern Section of the Society met at Geneva and Ithaca, N. Y., on June 22 and 23, 1932, with informal programs featured by the inspection of field plats, laboratories, and special facilities for work in agronomy at the State Experiment Station and the College of Agriculture. Short morning sessions each day were devoted to the presentation of summaries of the work in progress, by Dr. U. P. Hedrick, Director of the Geneva Station, and Dr. Cornelius Betten, Dr. J. A. Bizzell, and Dr. R. A. Emerson of Cornell. The afternoons were spent in looking over plat and field work. Attendance each day was about 65, and the sentiment of those attending was distinctly in favor of this type of summer meeting.

Some 55 attended the banquet in Geneva the evening of June 22, when Professor Bristow Adams of Cornell University spoke on his experiences on a recent trip around the world. Reports were presented from committees on soil organic matter, pastures, fertilizer ratios, and forage crop varieties. The following officers were elected for the ensuing year: *President*, Dr. F. D. Gardner, Pennsylvania State College; *Vice-President*, Prof. M. H. Cubbon, Massachusetts State College; and *Secretary-Treasurer*, Prof. H. C. Swift, University of Maine.

FILM STRIP PRICES

Prices for the film strips issued by the U. S. Dept. of Agriculture will be materially lower for the year beginning July 1, 1932, as compared with prices for the past year. The range in price will be from 14 to 85 cents, depending upon the number of illustrations in each series. Strips are available on such subjects as farm crops, farm forestry, plant diseases and pests, farm economics, farm engineering, adult and junior extension work, and other subjects. Lecture notes accompany each strip.

A list of available film strips and instructions on how to purchase them may be obtained by writing to the Office of Cooperative Extension Work, U. S. Dept. of Agriculture, Washington, D. C.

MEETING OF CORN BELT SECTION

With a total registration of 180, the summer meeting of the Corn Belt Section of the Society and of the American Society of Plant

Physiologists at the University of Wisconsin, Madison, Wisconsin, on July 11, 12, and 13, was a very successful event. The program was an exposition of the laboratory and field research on plants in progress at the College of Agriculture.

A BIBLIOGRAPHY ON ENVIRONMENTAL FACTORS IN RELATION TO PLANT DISEASE AND INJURY

The Ohio Agricultural Experiment Station has just issued as Technical Bulletin No. 9, under the authorship of Dr. J. D. Wilson, an extensive bibliography of papers in botanical literature, published both in this country and abroad, relating to the influences of environmental factors which are directly or indirectly harmful to plants. The citations are grouped alphabetically by senior authorship. Three indexes add materially to the value and usefulness of the bibliography. These are an environmental factor index, a host-disease-injury index, and an index to the scientific names of the host plants dealt with in the bibliography.

The publication comprises 203 pages, in paper covers, and sells for one dollar per copy.

PROGRAM FOR THE SOILS SECTION OF THE SOCIETY

Dr. M. F. Miller, chairman of the Soils Section Committee of the Society, announces that the committee is preparing for three symposia sessions and two sessions for general papers for the annual meeting of the Society in November in Washington. The symposia subjects will have to do with soil acidity, soil fertility plat experiments, and soil biology. The general papers will be limited to 15 minutes or less and in order to bring about some coordination in these general programs the committee desires that brief outlines of the papers be submitted to Dr. Miller at the University of Missouri, Columbia, Mo.

Also, abstracts of all papers must be in Dr. Miller's hands not later than October 1 for publication in printed form prior to the meeting.

THE CROPS SECTION AT WASHINGTON

Announcement was made in the June number of the JOURNAL of the plans for the program of the Crops Section of the Society in Washington next fall. Attention is again directed to the fact that information regarding the title, author, and time required for the presentation of papers before that Section should be sent to Dr. R. J. Garber, West Virginia University, Morgantown, W. Va., together with an abstract of the paper, not later than October 1.

NEWS ITEM

Dr. P. E. Brown has been made Head of the Farm Crops and Soils Department at Iowa State College and Head of the Farm Crops and Soils Section of the Iowa Agricultural Experiment Station. Dr. Brown has been Acting Head since last fall when Dr. W. H. Stevenson retired from the headship because of ill health.

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THE EFFECT OF POTASSIUM ON THE PRODUCTION OF PROTEINS, SUGARS, AND STARCH IN COWPEA AND IN SUGAR BEET PLANTS AND THE RELATION OF POTASSIUM TO PLANT GROWTH[1]

GEORGE JANSSEN and R. P. BARTHOLOMEW[2]

It has been shown (1, 2, 9)[3] that the plant may take up more potassium from the soil solution than is actually needed for normal growth. It has also been shown (6) that the potassium in the tomato plant is practically all water-soluble and that, being extremely labile, it can readily be retranslocated within the plant. The function of the potassium ion in plant metabolism is still a matter of conjecture. It appears from previous work (6), however, that there is not always a correlation between the percentages of sugars and starch in the plant and the heavier uptake of potassium. In some cases, it appears that the highest percentages of sugar and starch were produced at a potassium concentration which was also conducive for maximum growth; while in other cases high percentages of sugars and starch were found with a small uptake of potassium and with decreased plant growth. In nearly all cases, it was shown (6) that a high percentage of potassium in plants is associated with a lower percentage of total nitrogen and total water-soluble nitrogen than that found in plants which contain a low amount of potassium. These results suggested that potassium might be directly or indirectly concerned in the synthesis of proteins, that the lack of condensation of the amino acids to protein prevented growth, and that this in turn caused the high water-soluble nitrogen fraction.

It was the plan of the investigation reported here, therefore, to determine, if possible, the relationship between the amount of

[1]Contribution from the Department of Agronomy, University of Arkansas, Fayetteville, Ark. Published with the approval of the Dean of the College of Agriculture. Received for publication December 10, 1931.

[2]Assistant Agronomists.

[3]Reference by number is to "Literature Cited," p. 679.

potassium taken up by the plant and the production of the nitrogenous fractions (protein nitrogen, total nitrogen, total soluble nitrogen, and amino acids) and the carbohydrate compounds. A study was also made of the anatomical structure of plants grown in nutrient solutions containing high or low amounts of potassium.

METHODS

Cowpeas (*Vigna sinensis*) were chosen for the studies because they grow very rapidly, are well adapted to greenhouse culture, and, being a legume, produce a relatively high amount of protein. Sugar beets (*Beta vulgaris*) were grown to determine whether the percentage of sugar in the roots is materially increased with an increase of potassium in the plant.

The plants were grown in 2-gallon glazed jars containing 10 kilograms of sand. A nutrient solution previously described (6), was added to the plants at intervals of about 10 days. The nitrogen and potassium salts were kept in separate bottles and the low-nitrogen and low-potassium solution[4] contained only one-sixth as much nitrogen or potassium as did the full nutrient solution. The concentration of the complete nutrient solution after dilution is given in Table 1

TABLE 1.—*Concentration of nutrient solution expressed in equivalents per liter.*

BO_3	NO_3	NH_4	SO_4	PO_4
0.00546	0.03125	0.0890	0.05140	0.01985
Ca	K	Mg	Mn	Cl
0.0530	0.05375	0.0102	0.00074	0.117625

The diluted nutrient solution was added at the rate of 250 cc per jar at each application. To each 1,000 cc of solution, 5 cc of a 0.1% solution of ferric tartrate were added. Distilled water was applied from the top once or twice daily, as necessary to restore the optimum moisture content of the sand.

The sand and seed were sterilized before the seed was planted but in all cases large bacterial nodules developed on the roots of the plants. For this reason, the nitrogen results, for the low-nitrogen plants at the second analysis, are high.

[4]The terms "low-nitrogen" and "low-potassium nutrient solution," in contrast to "high-nitrogen" or "high-potassium," indicate that the former solutions contained only one-sixth the amount of nitrogen or potassium as did the latter or full-nutrient solution.

Forty-four jars were used in each of the first two series of experiments. Eleven of the jars were watered with a low-potassium nutrient solution, 11 with high-potassium solution, 11 with low-nitrogen solution, and 11 with a high-nitrogen solution. No low-nitrogen plants were grown in the third series.

One-half of the plants in the first series were harvested in early bloom and the remainder when the seed pods were beginning to form. Those in the second and third series were harvested in full bloom and when the growth of the pods had reached an advanced stage. All plant material which was used for carbohydrate analysis was fixed in boiling alcohol. The methods of analyses used in determining sugars, starch, and hemicellulose were the same as those described by Leukel (10) and Murneek (12). The nitrogenous fractions were determined on 50-gram green samples after the method described by MacGillivray (11). The precipitation of protein nitrogen was aided by the use of Stutzer's reagent. The amount of amino nitrogen was determined from a separate sample of green plant material by the Van Slyke method (5). All the material used for sectioning in paraffin was fixed in formal acetic alcohol. The sections were stained with Delofield hematoxylin. Free-hand sections were also made from green material which was collected at the time the plants were harvested.

Field experiments dealing with the effect of potassium fertilization on the production of sugar in the sugar beet plant were conducted on 1/50-acre plats at the University Farm. The fertilizer treatments were as follows: Two check plats received no treatment; four plats received nitrogen and phosphorus, but no potassium; four plats received nitrogen and phosphorus plus 150 pounds of muriate of potassium; four plats received nitrogen and phosphorus plus 300 pounds of muriate of potassium; and four plats received nitrogen and phosphorus plus 450 pounds of muriate of potassium.

Nitrogen was applied in nitrate of soda and ammonium sulfate at the rate of 150 pounds each per acre. Superphosphate, 16%, was applied at the rate of 300 pounds per acre. These rates of application had been found in previous experiments to give probable maximum yields.

PRESENTATION OF RESULTS

The results from the analyses of the experiments were averaged because they were similar. Thus, Table 2 contains the average of the percentage dry weights, carbohydrate compounds, and potassium from three series of cowpeas grown in sand cultures. Table 3 contains the average results of the nitrogen analyses of these same plants.

TABLE 2.—*Carbohydrate analyses of cowpea plants growing in sand cultures, the solution varying with respect to the potassium and nitrogen concentration.*

Treatment*	Part of plant	Dry weight %	Dry weight per plant, grams	Ether extract %	Reducing sugars %	Total sugars %	Starch %	Hemicellulose %	Total potassium %	Water-soluble potassium %
					Blossom stage					
HNHK	Leaves	12.25	0.94	7.39	3.24	4.32	4.74	6.44	2.38	2.25
HNHK	Stems	10.12	0.74	1.29	4.17	5.48	6.59	9.19	3.72	4.78†
HKLN	Leaves	10.50	0.46	1.75	3.27	4.90	7.73	7.88	3.07	2.45
HKLN	Stems	8.90	0.32	1.00	5.65	7.39	10.22	10.69	6.27	3.61
LKHN	Leaves	12.73	0.74	3.81	4.15	5.84	4.23	6.40	1.79	1.33
LKHN	Stems	11.78	0.44	0.99	6.77	8.34	6.09	8.91	1.90	2.57
LKLN	Leaves	12.00	0.56	1.98	3.58	4.83	5.53	8.13	1.58	1.59
LKLN	Stems	9.80	0.37	1.06	6.20	7.61	8.50	11.43	—	2.71
					Fruiting stage					
HNHK	Leaves	12.92	3.38	7.16	2.55	3.68	4.20	7.49	2.01	2.09
HNHK	Stems	13.75	3.60	0.80	3.42	5.14	11.88	10.81	3.35	3.22
HKLN	Leaves	12.09	2.91	5.80	2.32	3.43	4.49	6.37	2.26	1.72
HKLN	Stems	13.51	3.05	0.87	4.61	7.67	9.15	11.25	4.41	4.13
LKHN	Leaves	13.31	2.66	5.42	4.08	5.71	2.71	6.15	0.81	0.86
LKHN	Stems	15.50	2.48	1.26	4.46	6.38	8.98	10.48	1.06	1.06
LKLN	Leaves	13.00	2.97	6.57	2.84	5.83	3.48	6.34	0.78	1.19
LKLN	Stems	14.45	2.58	1.07	8.32	10.89	9.67	11.33	0.95	1.25

*In all tables the symbols indicate as follows: H = high; L = low; K = potassium; N = nitrogen.
†Increase may be due to the fact that a small sample was used.

TABLE 3.—*Nitrogen distribution of cowpea plants grown in sand cultures, the solution varying with respect to the nitrogen and potassium concentration.*

Treatment*	Part of plant	Dry weight %	Total nitrogen %	Water-soluble nitrogen %	Protein: Insoluble %	Protein: Water-soluble %	Protein: Total %	Nitrogen in filtrate %	Total nitrogen soluble %	Amino nitrogen %	Total potassium %
					Blossom stage						
HNHK	Leaves	12.25	4.48	2.00	2.74	1.27	3.76	0.71	44.0	0.414	2.38
HNHK	Stems	10.12	2.12	1.34	0.78	0.37	1.15	1.22	62.1	0.615	3.72
HKLN	Leaves	10.50	3.11	1.70	1.46	1.09	2.60	0.60	54.2	0.410	3.07
HKLN	Stems	8.90	1.23	0.36	0.65	0.15	0.80	0.26	47.1	0.482	6.27
LKHN	Leaves	12.73	4.31	1.97	2.38	1.14	3.52	0.73	44.4	0.452	1.79
LKHN	Stems	11.78	2.32	1.27	1.04	0.32	1.36	0.92	52.8	0.585	1.90
LKLN	Leaves	12.00	2.20	1.84	1.96	1.19	3.15	0.64	48.2	0.432	1.58
LKLN	Stems	9.80	1.86	0.58	1.28	0.10	1.39	0.49	32.7	0.303	—
					Fruiting Stage						
HNHK	Leaves	12.90	4.07	1.67	2.37	0.97	3.34	0.71	40.5	0.480	2.01
HNHK	Stems	13.75	1.89	0.92	1.45	0.45	1.41	0.52	46.3	0.409	3.35
HKLN	Leaves	12.09	3.91	1.65	2.18	1.07	3.45	0.49	41.9	0.545	2.26
HKLN	Stems	13.51	1.28	0.58	0.70	0.04	0.74	0.51	43.6	0.320	4.41
LKHN	Leaves	13.31	4.33	1.85	2.48	0.83	3.24	0.71	42.3	0.621	0.81
LKHN	Stems	15.50	2.41	1.29	1.45	0.41	1.87	0.87	52.7	0.651	1.06
LKLN	Leaves	13.00	4.06	1.62	2.43	1.13	3.57	0.57	36.0	0.539	0.78
LKLN	Stems	14.45	1.61	0.76	0.84	0.03	0.90	0.73	45.3	0.335	0.95

*See Table 2 for meaning of symbols.

Tables 4 and 5 contain the results of analyses of carbohydrate and of nitrogen compounds from two experiments on sugar beets grown in sand cultures. Table 6 embodies results of analyses of carbohydrate compounds from two series of sugar beets grown in Clarksville silt loam to which various amounts of potassium were added. Studies were also made of the anatomical structures of stems of high and low-potassium plants.

A study of the results obtained in the experiment shows again that there is no relationship between the percentage of potassium absorbed by the plant and the percentage of sugars present. This is in accord with results previously reported (1, 6, 7). (See Table 2.) It would appear that, in general, high percentages of sugars are not associated with high-potassium plants, but that the reverse condition is likely to occur. On the other hand, the percentage of starch is usually greater in the high-potassium plants than in the low-potassium plants. This fact would make it appear that there was a lack of condensation of the sugars to starch in case of plants which had received a small amount of potassium. The leaves of the low-potassium cowpea and sugar beet plants had a dark green color, were thickened and had a characteristic crinkling. This condition suggests a high osmotic pressure which might be caused by lack of condensation of sugars to higher carbohydrate compounds. Types of potassium leaf starvation may be noted in Fig. 1.

Potassium analyses were made on leaves which had died previous to the time the beets were harvested and also on green leaves at time of harvest. These results are given in a footnote to Table 4 It will be seen that about 45% of the potassium had been removed from the dead leaves previous to their death. This amount probably was translocated to new meristematic regions before the death of the leaves. This is in accord with the writers' previous finding (6) on

TABLE 4.—*Average analyses of two series of sugar beets which were grown in sand cultures, the solution varying with respect to potassium as indicated.*

Plant treatment*	Part of plant	Dry matter %	Dry weight per plant, grams	Reducing sugars %	Total sugars %	Starch %	Hemicellulose %	Total potassium %†
H K	Leaves	12.45	1.76	3.69	4.88	2.06	7.99	4.51
L K	Leaves	14.45	1.40	2.96	4.21	1.82	7.91	1.31
H K	Roots	13.57	4.28	7.80	27.60	3.12	9.68	2.21
L K	Roots	11.60	1.06	5.43	15.44	4.60	9.26	2.38

*See Table 2 for meaning of symbols.

†Potassium found in dead beet leaves of low potassium plants, 0.72%; potassium found in dead beet leaves of high potassium plants, 5.90%.

potassium translocation in tomato. These results showed that the basal dead leaves of the tomato plant in the late blossom stage contained only 0.38% of potassium in comparison with 1.18% potassium in the green leaves which remained on the stem at time of fruiting.

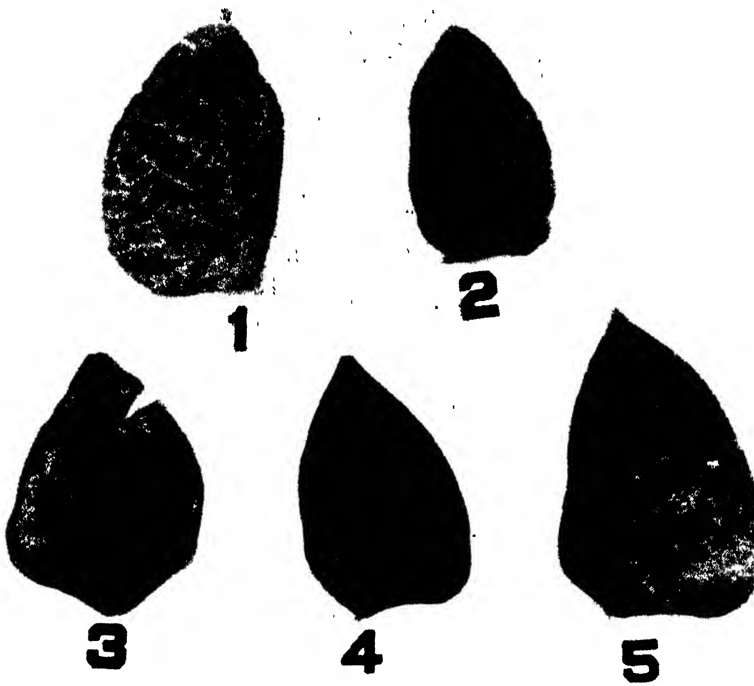

FIG. 1.—Leaves of cowpeas showing typical potash starvation symptoms. 1, 4, and 5, showing effects of potassium starvation; 2 and 3 normal leaves.

A comparison between the percentage of potassium and sugar in sugar beets grown in the field (Table 6) and those grown in nutrient cultures (Table 4) shows that there is no relation between the percentage of sugars and the percentage of potassium in the plant. The percentage of potassium in the beets grown on soil which received no fertilizer is lower than the percentage of potassium in beets grown on the low-potassium nutrient solutions, whereas the percentage of sugar in the former beets is the higher. The sugar content of the beets grown on unfertilized soil is also larger than the sugar content of beets grown on soils fertilized with nitrogen phosphorus and potassium fertilizers, whereas the potassium content of the beets is the lowest

TABLE 5.—*Nitrogen distribution of sugar beets grown on sand culture, the solution varying with respect to potassium concentration.**

Treatment†	Part of plant	Dry weight %	Total nitrogen %	Water-soluble nitrogen %	Protein			Nitrogen in filtrate %	Amino nitrogen %	Total potassium %
					Insoluble %	Water-soluble %	Total %			
H K	Leaves	12.55	4.02	1.37	2.65	0.17	2.72	0.93	0.416	4.51
L K	Leaves	13.50	5.29	1.78	3.51	0.28	3.79	1.50	0.594	1.31
H K	Roots	15.00	2.02	1.44	0.58	0.11	0.69	1.35	1.460	2.21
L K	Roots	11.90	2.62	1.60	1.02	0.15	1.17	1.52	1.640	2.38

*Analyzed on Oct. 8, 1929, when 120 days old.
†See Table 2 for meaning of symbols.

of all treatments. The sugar beets receiving 150 pounds of muriate of potash in the fertilizer mixture had a larger sugar content but a smaller percentage of potassium than the beets receiving either 300 or 450 pounds of muriate of potash in the fertilizer mixture. This difference in behavior might be explained on the basis that the growth behavior brought about by increased potassium resulted in larger beets but not in sugar content.

TABLE 6.—*Average of two years' results on carbohydrate analyses of sugar beet roots grown on Clarksville silt loam to which various amounts of potassium was added as indicated.*

Treatment	Dry weight %	Reducing sugars %	Total sugars %	Starch %	Hemi-cellulose %	Total potassium %
Check....	12.75	15.42	49.81	3.27	7.81	1.65
N P. ...	10.62	13.64	46.88	3.69	7.66	2.69
N P+150 lbs. K	10.79	12.22	48.92	3.77	7.86	3.13
N P+300 lbs. K	10.42	12.48	42.33	4.27	7.57	3.69
N P+450 lbs. K	9.91	13.34	44.00	3.05	8.20	4.14

Marked differences were noted in the growth in favor of the plants fertilized with the higher amounts of potassium. The above results differ markedly from the results observed in beets grown in sand culture where an increase of 79% in total sugars of the roots was found in the case of high-potassium treatment over low-potassium treatment. It was quite evident that malnutrition resulting from a potassium starvation had taken place in the case of beets grown on the low-potassium nutrient solution, and that this was largely responsible for the low percentage of sugar in these beets. It should be noted that the dry weight per plant of those receiving the potassium treatment is about 75.4 times as great as that of those receiving the low-potassium treatment. The relative difference in size of beets grown in high- and low-potassium nutrient solution is shown in Fig. 2.

The nitrogen data are given in Table 3. These results substantiate previous findings, namely, that the low-potassium plants are frequently high in total nitrogen. The percentages of amino acid are in the majority of instances as high in the potassium-deficient plants as in the high-potassium plants, indicating quite clearly that this was not limiting plant growth. The results indicate that the high-potassium plants do not contain a greater percentage of protein than the low-potassium plants. The percentage of insoluble proteins and total proteins in the stems of the low-potassium plants is higher than that in the leaves of high-potassium plants. These results seem to indicate that potassium, at least under the conditions in the present investigation, is not necessary for protein synthesis.

An anatomical study was made of stems of plants grown in a high- and a low-potassium nutrient solution. This study revealed that

FIG. 2.—Sugar beets grown in sand cultures containing low and high potash concentration. 1, grown on full potassium concentration; 2, grown on one-eighth the normal or full potassium concentration.

the cell walls of the low-potassium plants are thicker than the cell walls of high-potassium plants. Further, the sclerenchyma cells were

found to be more numerous in the stems of both cowpea and soybean plants grown on a low-potassium nutrient solution than in plants grown on a high-potassium nutrient solution. Not only were the sclerenchyma cells more numerous, but the wood fibers were thicker and the cortex cells fewer and smaller. Cross sections of these low-potassium roots revealed an extensive development of the mechanical tissue in the vascular system which resulted, apparently, in a more woody plant. In most of the plants sectioned the cortical cells of the high-potassium plants were more numerous and in a more active state of division than those of the low-potassium plants. There also seemed to be less thickening of the cell walls in cells of the high-potassium plants. Nightingale, *et al* (13) have suggested that thick cell walls in the low-potassium plants are due to, or associated with, high carbohydrate content in the low-potassium plants, and that the high carbohydrate content is due to lack of nitrate assimilation. It seems probable, therefore, that potassium affects indirectly the nature of cell wall formation.

Results of an anatomical study of the corn, sugar beet, Sudan grass, cowpea, and soybean plants indicate that a lack of potassium is associated with thick cell walls, which, in turn, may very likely be due to the high percentage of carbohydrate compounds present in these plants. This increased thickening of the cell wall may be a natural result of the deposition of carbohydrate compounds which would otherwise, if potassium were present, have been directed to new cell growth.

The results from the analyses made for sugars, starch, and various nitrogenous fractions, indicate that low-potassium plants, as a rule, contain as high a percentage of these compounds, if not higher, than the high potassium plants. It appears, therefore, that these compounds do not limit plant growth in the low-potassium plants. Kraus and Kraybill (8) and others have shown that the vegetative or reproductive conditions of some plants is often associated with the carbohydrate and nitrogen relationship. For example, a relatively high percentage of nitrogen associated with an available supply of sugars and starch in the plant may lead to a vegetative and probably succulent plant. In view of this fact, it should be noted that in the present experiment, and in others previously reported (6) and (7), the percentages of sugars, starch, and nitrogen could not have been limiting factors of growth in the potassium-deficient plants, since, as has already been stated, these compounds were usually as high as or higher than in the high-potassium plants. Under such conditions, plant growth should proceed normally if the carbohydrate nitrogen

relationship alone were concerned. This it did not do, and therefore it is evident that potassium is a limiting factor in growth.

How then does potassium function in the plant? It has been inferred in a previous publication (6) that potassium might be associated with cell division, since it is found in large amounts in actively growing regions of the plant and in the cambium of the potassium-starved plants. It was also noted (6) that stems of tomato low in potassium grow in length but not in diameter. This kind of growth in potassium-deficient plants seems to be directly associated with the translocation of potassium to meristematic regions. These findings are in accord with those obtained by Dowding (3), who found potassium (chloroplatinate crystals) localized in the meristematic and embryonic tissues.

Schermerhorn (14) and others have shown quite clearly that sweet potatoes fertilized with potassium are large and "chunky," while those not fertilized with potassium are long and thin. Thus, "The chunky potatoes possessed a large active primary cambium region,*** whereas the long thin potatoes were practically without a primary cambium,***. In other words, the relatively large diameter of the chunky sweet potato is directly due to the rapid formation of new cells produced by the primary cambium." In a later paper (13), similar conclusions are presented.

In the present paper, it has been shown that the percentage of total proteins of the potassium-deficient plants are as high as those in the high-potassium plants. Similar results were obtained by Nightingale *et al.* (13). He suggests, however, that potassium is necessary for the synthesis of the proteins of the meristematic tissue. This seems logical in view of the fact that the percentage of meristematic tissue was found to be lower in potassium-deficient plants than in plants which had access to sufficient potassium. Similar results were obtained by the writers, as has previously been noted, namely, a reduced development of pericycle in the sugar beet and a lessened degree of cortical cell division in the soybean plant, together with a smaller size of these cells after cell division.

SUMMARY

The investigation described in the foregoing pages deals with a study of the relation between sugars, starch, and nitrogen distribution of cowpea and sugar beet plants which had been grown on high- and low-potassium nutrient solutions. An anatomical study of these plants was also made.

1. It shows that the greatest percentage of potassium is taken up in plants which were given the heavier potassium application.

2. Analyses for carbohydrates has shown that cowpea plants grown in a low-potassium nutrient solution, as a rule, were higher in reducing sugars and total sugars and lower in starch than those grown in high-potassium nutrient solutions.

3. The total percentage of nitrogen was usually greater in the low-potassium plants than in the high-potassium plants. The percentage of protein nitrogen also was usually greater for the potassium-deficient plants than in the high-potassium plants. This was particcularly true in the case of stems.

4. From the results presented, it appears that nitrogen, sugars, and starch are not limiting factors for growth in potassium-deficient plants. The percentages of these compounds were usually as high in potassium-deficient plants as in high-potassium plants.

5. In nearly all instances the percentage of amino nitrogen in the low-potassium plants was as great as or greater than that in the high-potassium plants.

6. The anatomical study of cowpeas and soybeans shows that thick cell walls are associated with low-potassium in the plant. In general, there seems to be a greater development of the sclerenchyma cells and mechanical tissue of the vascular system and a smaller development of the cortex cells, both in number and size, in the low-potassium plants than in the high-potassium plants.

7. In the sugar beet, it appears that the cell walls of the mechanical tissue of the vascular system are thicker and more numerous in the low-potassium plants than in the high-potassium plants; also that the pericycle activity was reduced in the former plants.

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A COMPARISON OF METHODS FOR DETERMINING THE AVAILABILITY OF PHOSPHORUS[1]

H. J. SNIDER[2]

A number of methods are in use to determine the need of the soil for additional phosphorus. Some of these methods are so designed that their results may be exrpessed quantitatively with considerable accuracy and therefore comparisons may be made of their relative value.

The three methods compared in this paper are the Neubauer (4)[3] plant seedling method, the Truog (6) quantitative chemical method, and the field trial method. The field trial is probably the oldest method for determining the need for phosphorus and is used in this investigation as the guiding standard for measuring the possibilities of the other methods.

In the operation of the Neubauer method modifications were avoided and an effort was made to follow as closely as possible the plans of its originator. The operation of this method is well described by Neubauer (4), Thornton (5), Fudge (2), Harris (3), and others.

In the Truog method the soil was extracted for 30 minutes with N/2000 H_2SO_4 solution buffered to pH 3. Two grams of soil were used to 400 cc of extracting solution.

[1]Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director. Received for publication January 6, 1932.

[2]Assistant Chief, Soil Experiment Fields.

[3]Reference by number is to "Literature Cited," p. 685.

The wheat yields reported in Tables 1 and 2 were obtained from a series of which the individual plats were 80 by 48 inches in size, and of sufficient number that each treatment was replicated five times. At harvest 10 square feet of the wheat was removed from the center of the plat for yield determinations. This method is fully described by Bauer (1). The plan of treatment was designed to compare different carriers of phosphorus as well as different acre rates of application and fineness of grinding of rock phosphate. The first application of the phosphates was put on in the fall of 1927 at the time of seeding wheat. The first wheat crop in 1928 was followed by red clover. In the fall of 1929 the land was again seeded to wheat; also a second application of phosphate fertilizers was put on at this time. Both applications of fertilizers were made by hand along the drill rows and worked into the soil. The size and arrangement of these plats were such that all operations were performed by hand labor except the seeding of the wheat, which was seeded with an 80-inch disc drill.

TABLE 1.—*Kewanee field, comparison of methods for determining the availability of phosphorus.*

Treatment	Acre rate of application, pounds	Wheat yield, bushels,	Neubauer method, mgm P	Truog method, p. p. m.	Phosphorus in grain %
None	——	30.7±0.7	1.25	8	0.300
Superphosphate	507	44.6±1.3	2.25	17	0.375
Treble superphosphate	280	49.0±2.6	2.25	22	0.400
Rock phosphate	1,026	43.0±1.3	1.65	49	0.350
Rock phosphate	2,000	51.6± .5	2.75	185	0.375
Rock phosphate	4,000	52.0±2.4	3.56	255	0.400
Rock phosphate (65% through 100 mesh)	1,500	47.0±2.0	2.00	76	0.350
Rock phosphate (99% through 100 mesh)	1,500	48.6±1.8	2.63	118	0.350

TABLE 2.—*Joliet field, comparison of methods for determining the availability of phosphorus.*

Treatment	Acre rate of application, pounds	Wheat yield, bushels	Neubauer method, mgm P	Truog method, p. p. m.
None	——	21.2± .5	1.50	9
Superphosphate	507	43.1± .8	3.50	19
Treble superphosphate	280	46.1±1.0	3.75	23
Rock phosphate	1,026	35.1±1.0	3.00	41
Rock phosphate	2,000	40.0±1.9	3.00	70
Rock phosphate	4,000	44.5± .7	3.00	175

Soil samples were collected approximately 6 weeks after the 1929 wheat was seeded. The borings were taken to a depth of about 7 inches, and each sample was a composite of 20 cores, taking four from each of five replicated plats representing a single treatment.

The rock phosphate used in this experiment contained 14.9% phosphorus (P) and 95% passed a 100-mesh sieve, except on plats, where the fineness is otherwise noted. The superphosphate was a 20% P_2O_5 grade and the treble superphosphate a 45% P_2O_5 grade. The acre rates given in Tables 1 and 2 represent the total of the two applications made in 1927 and in 1929. The 507 pounds of superphosphate, the 280 pounds of treble superphosphate, and the 1,026 pounds of rock phosphate represent equal money values of these three carriers. No lime or other fertilizing material were added to these plats.

The Kewanee field represents the soil type Muscatine silt loam. The results secured by both the Neubauer and the Truog methods as reported in Table 1 indicate low availability of phosphorus on the untreated soil. The acre yield of 30.7 bushels of wheat does not necessarily signify that this soil is deficient in available phosphorus, but the increase in the yield due to the addition of phosphorus seems to indicate a deficiency of this element.

The Joliet field represents Clarion silt loam. Data presented in Table 2 show that the untreated soil on this field is low in available phosphorus, as determined by the Neubauer and the Truog methods. The comparatively low yield of 21.2 bushels of wheat on the untreated soil would seem to indicate a deficiency of some plant food element, and the addition of phosphorus showed that this element apparently filled the need.

It was suggested by Thornton (5) that 4 mgm P_2O_5 be used as the limit value for available phosphorus as determined by the Neubauer method. This amount of P_2O_5 is equivalent to 1.75 mgm of elemental phosphorus. The Neubauer results from the untreated soils in Tables 1 and 2 were well below this figure and tend to support Thornton's suggestion. It might be more desirable when Neubauer results are reported as elemental phosphorus (P) to place this limit value at 2 mgm.

Superphosphate and treble superphosphate increased the wheat yield on both fields. The Neubauer method showed increased availability over the check for these two phosphates, with the higher availability on the Joliet soil. The Neubauer results in all cases with these two phosphates were well over the 2-mgm limit value. The results by the Truog method for the two soluble phosphates were

very similar on both fields. These latter results indicate that the availability of superphosphate and treble superphosphate should be well over 20 p.p.m., or 40 pounds an acre, before sufficient available phosphorus is in the soil for maximum wheat yields on soils such as here represented. These results further indicate that the lower limit of availability by the Truog method lies between 8 and 17 p.p.m. of available phosphorus. These tables do not furnish sufficient data to determine exactly where this point is.

The applications of treble superphosphate added approximately 10 pounds an acre more phosphorus than was added by the superphosphate. Either this additional phosphorus or perhaps the higher availability of the treble superphosphate was reflected both in the wheat yields and in the Truog results on both fields. The Neubauer method showed the difference on the Joliet soil, but failed to show it on the Kewanee soil.

The three different amounts of rock phosphate (1,023 pounds, 2,000 pounds, and 4,000 pounds) gave a progressive increase in wheat yield for each additional increment in the amount of phosphate applied. On the Kewanee field the Neubauer results corresponded in availability with the increase in wheat yield. On the Joliet field the Neubauer results failed to show a difference in availability corresponding to the different amounts of rock phosphate applied.

The results of the Truog method showing the availability of the three amounts of rock phosphate varied on both fields in correspondence with wheat yields. The lowest availability was with the smallest amount of phosphate, increasing progressively up to the largest amount. The Truog results on the Joliet field showed increase in availability proportionately more uniform for the three amounts of phosphate than did the results from the Kewanee field. This difference or irregularity might possibly have been due to the great difficulty in obtaining representative soil samples from plats rather recently treated with finely ground rock phosphate.

The measurement of solubility of the rock phosphate by the Truog method was considerably higher than that of the superphosphate or the treble superphosphate, although where the smaller amounts of rock phosphate were used the wheat yields indicated need for additional phosphorus. In the operation of the Truog method the soil and phosphate are very thoroughly mixed so that the extracting solution is in effective contact with every particle of rock phosphate. Such an ideal condition for solubility of the phosphate may never exist under conditions of plant growth in the field.

The wheat yields in Tables 1 and 2 indicate that under the condi-

tions of this experiment the availability of rock phosphate by the Truog method should indicate well over the 75 p.p.m. or 150 pounds an acre of available phosphorus before sufficient is present for maximum wheat yields. The upper limit value apparently need not under these conditions exceed 185 p.p.m. available phosphorus.

With the Neubauer method, according to these data, the upper limit beyond which additional phosphorus did not increase the wheat yield for either kind of phosphate was at 3.50 mgm or above.

The two degrees of fineness (65% through 100 mesh and 99% through 100 mesh) of rock phosphate show in Table 1 some difference in the yields of wheat with, however, only slight advantage to the finer grade. Both Neubauer and Truog tests showed rather decided superior availability of the finer grade of rock phosphate.

The percentage phosphorus found in the grain on the Kewanee field showed considerable correlation with the wheat yield and phosphate treatments. The correlation coefficient between the wheat yield and percentage phosphorus was 0.8 calculated by the "rank difference" method as described by Gavett.[4] In the application of the rank difference method the correlation becomes more significant as the coefficient approaches unity.

The data from the Kewanee field in Table 1 have a correlation coefficient of 0.917 between the wheat yield and the Neubauer results calculated by the rank difference method, and 0.81 between the wheat yields and Truog results. The Joliet results in Table 2 have a correlation coefficient of 0.88 between the wheat yields and the Neubauer results, and 0.38 between the wheat yields and Truog results. The lower correlation coefficient for the Truog results was probably due to the greater solubility of rock phosphate by the laboratory method of extraction previously referred to.

SUMMARY

The results obtained by the Neubauer and Truog methods for determining the availability of phosphorus compared favorably with the wheat yields obtained on phosphate-treated plats.

Each of the methods showed that the soils examined were deficient in available phosphorus, and indicated also the lower limits where more phosphorus should be added as well as the upper limits beyond which additional phosphorus need not be added to these soils.

The three methods, except in one comparison, showed a difference between superphosphate and treble superphosphate due either to a

[4]First Course in Statistical Methods, pages 243–244.

larger amount of phosphorus added or a higher availability of the treble superphosphate.

The larger amounts of rock phosphate compared favorably with the superphosphate and treble superphosphate both in wheat yield and in the Neubauer results. The Truog method showed considerably higher results with the larger amounts of rock phosphate in comparison with the superphosphate and treble superphosphate probably due to the method of extraction.

The different amounts of rock phosphate (1,023 pounds, 2,000 pounds, and 4,000 pounds) showed an increase in wheat yield for each increment of phosphate added. The Neubauer method showed an increase in milligrams of phosphorus for each additional increment of rock phosphate added on the Kewanee field, but failed to show this difference on the Joliet field. The Truog results show a progressive increase in solubility of phosphorus for each additional increment of rock phosphate used.

In the comparison of the two degrees of fineness (65% through 100 mesh and 99% through 100 mesh) of rock phosphate the three methods gave results favorable to the finer grade.

The percentage of phosphorus in the grain showed rather good correlation with wheat yields and phosphate treatments.

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THE USE OF THE TROEMNER BALANCE FOR MEASURING THE UPPER PLASTIC LIMIT OF SOILS[1]

L. D. Baver[2]

Perhaps the greatest criticism of the use of the Atterburg constants for characterizing soil consistency has been due to the personal factor in making the determinations. This has been especially true of values for the upper plastic limit. The upper plastic limit is defined as that moisture content at which the soil will just barely flow under an applied force. The force used in the usual method is produced by the arm of the investigator as he strikes a dish containing the plastic soil against the palm of the hand or a rubber stopper. If the small groove which was cut into the plastic mass just barely flows together as a result of this impact the correct moisture content of the upper plastic limit has been obtained.

It has been shown that each investigator can duplicate his own results but that different investigators vary considerably in the data they obtain. This should be expected if one considers the difficulties involved in trying to standardize the amount of force in the swinging arm of different observers. The moisture content of the upper plastic limit would be expected to vary with the number of impacts, the force applied in the impact, the amount of soil in the dish, and the width of the groove. All of these factors are naturally influenced by the personal element. It is obvious, therefore, that a standardization of the technic of determining the upper plastic limit to eliminate the personal element is highly essential in order to strengthen the value of the determination.

Roberts[3] has suggested the use of small glass cups for making these measurements. These cups are made from ordinary 100-cc graduate cylinders which have been cut off at the 5 cc mark. A V-shaped groove, 4 mm deep and 4 mm wide at the top, is cut into the top of the cylinder. This standardizes the size of the groove which is cut into the soil. Roberts used the weights of iron cylinders of various sizes to provide the desired force for making the soil flow together. The data in this paper were obtained by a modification of

[1]Contribution from the Department of Soils, University of Missouri, Columbia, Mo. Published with the approval of the Director of the Missouri Experiment Station. Journal Series No. 326. Received for publication January 7, 1932.

[2]Assistant Professor of Soils. The writer wishes to express his sincere appreciation to his laboratory assistant, George Browning, for aiding him in this study.

[3]Roberts, R. C. A suggested method for the determination of the upper plastic limit of soils. Bul. XI Amer. Soil Survey Assoc., 56–60. 1930.

Roberts' method, using a Troemner balance as a means of applying the desired force.

The experimental arrangement for determining the upper plastic limit is shown in Fig. 1. The soil is thoroughly kneaded and mixed into a thick paste in a porcelain evaporating dish and transferred to the glass cup, A. The soil is firmly squeezed into the cup and the

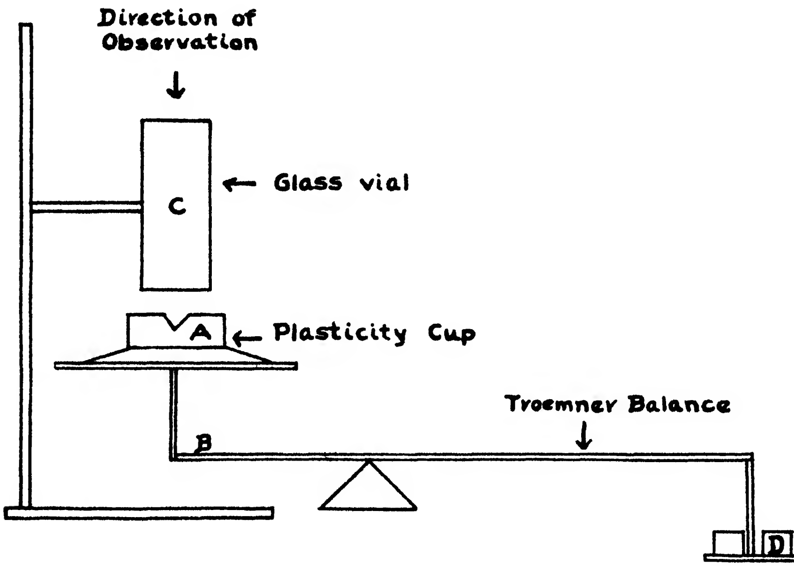

FIG 1.—Apparatus for determining the upper plastic limit.

surface is made level with the top of the cup. The groove is cut into the soil paste by using a porcelain or wooden spatula which is so beveled that it fits the groove in the cup. After the groove has been clearly cut, the cup is placed on the Troemner balance, B. A glass vial, C, the diameter of which is slightly smaller than the inside diameter of the cup, is lowered until it just touches the surface of the soil. The weight, D, is then placed on the balance which exerts a given force on the soil in the cup and causes the groove to flow together. Observations of the amount of flow are made from above through the bottom of the glass vial. The moisture content at which the soil will barely flow together is called the upper plastic limit. It was found that a weight of 1,000 grams on the balance exerted sufficient force to give results comparable with those obtained by the hand method.

There are several advantages in the use of this apparatus, *viz.*, the amount of force applied can easily be varied; any given weight will

always exert the same force; observations of the amount of flow are easily and accurately made; and, finally, the Troemner balance is a common laboratory apparatus. This technic reduces the personal error to a minimum and should prove valuable in soil consistency measurements.

A study was made of the effect of different weights upon the moisture content at which flow was produced. These data are shown

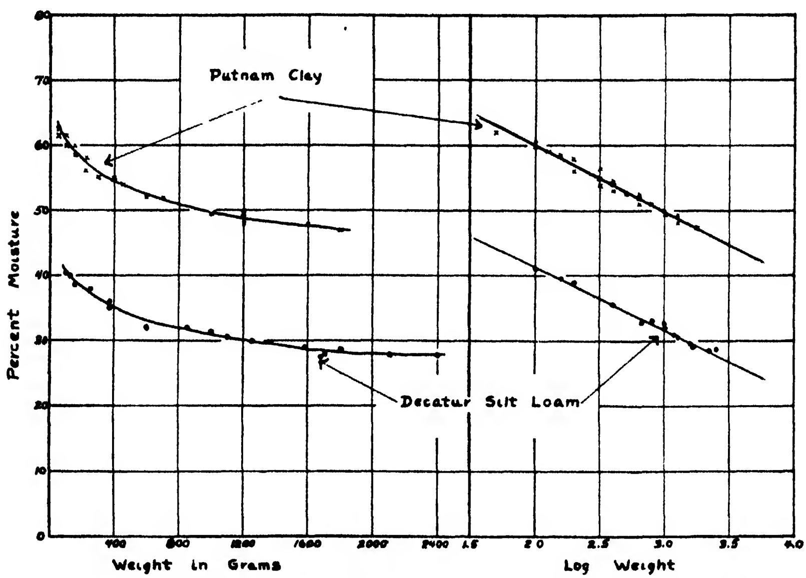

FIG. 2.—The relation of the moisture content of the soil to the force required to produce flow.

in Fig. 2. The moisture content at the point of flow decreases with the force applied. This relationship is logarithmic as shown in the second part of Fig. 2. The fact that a straight line is obtained when the logarithm of the weight applied is plotted against the moisture content permits a rapid determination of the upper plastic limit. Since a weight of 1,000 grams on the balance apparently gives values corresponding to those obtained by the hand method, one may choose either of two ways in making the determination. First, the moisture content can be so adjusted that flow is obtained with the use of 1,000 grams. Second, one can mix up the soil into a paste, determine what weight is necessary to make the soil flow, and then plot the moisture content against the logarithm of the weight. By using three or four different mixtures a straight line can be drawn through the points and the moisture content corresponding to the logarithm 3

(logarithm of 1,000) would be that of the upper plastic limit. A comparison of these two methods of using the balance is given in Table 1. The "observed" values were obtained with 1,000 grams on the balance. The "calculated" values were obtained by plotting the logarithms of the weight on the balance against the moisture content of the soil. The data show that there is a very good agreement between the two methods. Of course, using 1,000 grams as a constant weight and adjusting the moisture content would be more accurate.

TABLE 1.—*Comparison of values for the upper plastic limit determined by various methods.*

Soil No.	Hand method	Balance method	
		Observed	Calculated from graph
21	68.1	64.9	66.5
22	39.5	41.7	42.5
23	44.2	45.8	46.0
24	21.2	23.6	23.5
25	50.6	50.0	50.0
26	42.3	38.0	38.5
27	31.4	33.5	31.5

TABLE 2.—*Comparison of the hand and balance methods for determining the upper plastic limits.*

Soil No.	Moisture content of the upper plastic limit, % moisture				% variation of B from A		% variation of hand from balance method	
	Hand Method		Balance Method					
	Investigator A	Investigator B	Investigator A	Investigator B	Hand method	Balance method	A	B
1	23.8	24.4	25.0	25.4	+2.5	+1.7	—4.8	—3.9
2	37.1	38.7	39.5	40.8	+4.3	+3.3	—6.1	-5.1
3	32.3	28.9	30.0	30.3	—10.5	+1.0	+7.7	—4.6
4	42.8	40.2	42.5	43.5	—6.1	+2.3	+0.7	—7.7
5	58.7	56.1	56.0	56.0	—4.4	0.0	+1.2	+0.2
6	25.5	25.2	27.0	26.6	—1.2	—1.5	—5.5	—5.2
7	35.0	33.5	35.5	35.1	—4.3	—1.1	—1.4	—4.4
8	45.6	42.4	42.5	43.4	—7.0	+2.1	+7.3	—2.3
9	24.7	24.2	25.5	24.3	—2.0	—4.7	—3.1	—0.4
10	31.9	30.5	32.0	30.2	—4.4	—5.6	—0.3	+1.0
11	40.5	39.7	41.0	39.3	—2.0	—4.1	—1.2	+1.0
Average					4.43%	2.49%	3.57%	3.25%

A comparison of results obtained by two investigators with the hand and the balance methods is given in Table 2. These data show two significant facts. First, that there is an excellent agreement be-

tween the hand and balance methods by both investigators. The average variation of the hand from the balance method was 3.57% and 3.25%, respectively, for investigators A and B. These results were obtained with widely different soils. Secondly, that the agreement between the results of A and B were much better when the balance method was used. This should be expected if the personal error is minimized in the balance method. The average variation of B from A was 4.43% with the hand method and 2.49% with the balance method. The maximum variation with the former method was 10.5%; with the latter method 5.6%. The variation in the results of the hand method might be expected to be larger between investigators working in different institutions. These data were obtained by different observers in the same laboratory where the technic was standardized as closely as possible. The data show, however, that duplication of results is more nearly possible when the personal error is decreased. The use of the Troemner balance appears to be most advantageous for reducing this error.

THE EFFECT OF ADDITIONS OF NITROGEN ON THE DECOMPOSITION OF SUGAR CANE TRASH UNDER FIELD CONDITIONS[1]

MADISON B. STURGIS[2]

Sugar cane trash is the material left on the surface of the ground after harvesting sugar cane and consists of all the leaves and the upper immature part of the stalk. In 1930 there were 184,000 acres of sugar cane harvested in Louisiana which gave an average yield of 17.0 tons of mill cane and 8.3 tons of trash per acre. This trash crop contained 40 pounds of combined nitrogen per acre. It also contained 2,800 pounds of hydrolyzable carbohydrates which have the potential capacity of inducing the fixation of 26 pounds of nitrogen per acre through the stimulation of nitrogen-fixing forms of the

[1]Contribution from the Department of Soils, Louisiana Agricultural Experiment Station, Baton Rouge, La. Also presented before Section O of the American Association for the Advancement of Science, at New Orleans, Louisiana, December 29, 1931. Published with the approval of the Director of the Louisiana Agricultural Experiment Stations. Received for publication January 16, 1932.

[2]Assistant Soil Technologist. The author wishes to acknowledge his indebtedness to W. G. Taggart for many valuable suggestions and for supervision of the field work, to W. P. Denson for assistance with the analytical work in the beginning, and to Dr. P. M. Horton for helpful criticisms and suggestions given in the progress of the investigations.

Azotobacter type. However, this fixation value is only tentative as it is based on laboratory conditions.

The nitrogen content of wide areas of the alluvial soils which are planted to sugar cane has been so reduced that the application of 40 pounds of nitrogen per acre annually is a requisite to profitable yields. Although legumes are being effectively used in the maintenance of soil nitrogen in the cane belt, the relatively high removal of nitrogen from the soil under the conditions that prevail in the growing of sugar cane makes desirable the use of all crop residues for the support of the highest state of soil fertility. The purpose of this experimental work has been to determine the conditions under which sugar cane trash can be utilized in conserving the soil nitrogen and organic matter without the lack of available nitrogen for crop growth ensuing from the excessive stimulation of soil micro-organisms.

Sugar cane planters commonly burn the trash for the utilization of it presents practical difficulties. The trash is very bulky and difficult to plow under or to plow through in the cultivation of the crop. If it is buried or plowed under deeply, the decomposition is too slow for the crop immediately following to benefit from its use. There are also the possibilities that should the trash remain undecomposed it may serve to protect the resting stage of the sugar cane borer and that under conditions of excessive moisture and low temperature its presence may increase the infection of corn and cane roots by facultative parasitic fungi in the soil.

Bonazzi (3)[3] observed through direct microscopic examination that the addition of cane trash to soils increased the numbers of micro-organisms, but that the type of cells did not change. When only the water-soluble, alcohol-soluble fraction of trash extract was added, a marked increase in the numbers and varieties of forms occurred. The non-symbiotic nitrogen fixing bacteria of the *B. amylobacter* type increased in numbers and activity. Bonazzi found that Azotobacter did not utilize the complex energy materials of trash directly, but, that when trash was acted on by a native flora which apparently liberated simpler forms of carbohydrates, Aztobacter could in succession fix nitrogen in a nitrogen-poor medium. He also found that nitrate accumulation in the soil was much higher when the trash was left on the surface than when trash was incorporated in the soil.

Owen and Denson (12) noted that nitrates were depressed for

[3]Reference by number is to "Literature Cited," p. 706.

over 8 weeks in soil cultures to which 2% of fresh trash had been added. They also observed that the fresh trash-soil cultures increased considerably in total nitrogen and attributed the increase to nitrogen fixation. These investigators observed that the removal of the lignin fraction (alkali extract) increased the rate of decomposition of the residual material and so questioned the results of the continued use of large amounts of cane trash on the accumulation of the more resistant lignin material and its effects on the productivity of the soil.

Bonnet (4) studied the decomposition of the various fractions of composted cane trash and found that the addition of inorganic nitrogen to the composted trash hastened its decomposition. Practically all the nitrogen present and added was recovered. There was no loss of nitrogen by volatilization or reduction, but a slight increase in total nitrogen in the compost to which no nitrogen was added.

Jensen (7) added 2% each of straw and farmyard manure to a neutral soil and found that when the supply of readily available energy material is exhausted the bacterial numbers drop and the production of mineral nitrogen begins This occurred within 100 to 125 days after the soil had been treated. The nitrate depression which was caused by the straw and manure was very marked at first but gradually wore off and at the end of 300 days the nitrate content reached the level of the control soil.

The work of Nelson (11) shows that plant residues and their extracts may kill the nitrifying organisms and inhibit oxidation. Soluble organic matter was found to be toxic to the nitrifiers under conditions where there was no oxidation.

Flor (6) observed that the severity of the root rot of sugar cane and corn caused by species of Pythium, which are facultative parasitic fungi living readily on dead organic matter, varies to a great extent. Pythium is favored by lower temperatures and high moisture content of the soil. "The effect of the fungus was severe only in soils with a water content greater than 50% of the moisture-holding capacity." Excessive moisture in summer does not cause so much harm as in winter and spring.

There are several important factors that will limit the utilization of cane trash. Considerable time will be required for the material to decompose sufficiently to prevent a lowering of the available nitrogen in the soil. Good drainage, aeration, and an intimate mixture of the material with the immediate surface soil are necessary to insure desirable decomposition and to prevent a lowering of the oxidation-reduction potential of the soil. The soil will gain in total nitrogen

from the addition of cane trash, especially fresh trash, but the nitrogen that becomes synthesized into microbial protoplasm will become gradually available.

METHODS OF EXPERIMENTATION

Two series of 20 plats each were used. The soil in these plats is a Sharkey silty clay loam. The plats of the first series were of 1/2000 acre size and closely controlled, except for leaching losses, by water-tight walls of asphalted boards which were sunk into the soil 4 inches deep and extended 4 inches above the surface. The field plats in the second series were 1/20 acre in size and were adjacent to the controlled plats. Yield results were obtained from the field plats. Corn had been grown on all these plats in 1929 and the corn stalks turned under in the fall previous to the beginning of this experiment. The soil and soil conditions, except that there was no run-off from the controlled plats, were representative of the sugar belt.

Both series of plats received five treatments with four plats out of each series receiving the same treatment, so that the results reported under each treatment are the average of four plats. The first treatments were applied March 10, 1930, and were as follows:

1. Check, no treatment.
2. 12 tons of moist field trash, 80 pounds N and 40 pounds P_2O_5 per acre.
3. 12 tons of moist field trash and 80 pounds N per acre.
4. 12 tons of moist field trash and 40 pounds N per acre.
5. 12 tons of moist field trash per acre.

The nitrogen was added as ammonium sulfate and the phosphorus as superphosphate.

At the second application of trash and fertilizer on October 27, 1930, the phosphorus was omitted in treatment No. 2 and the controlled plats under treatment No. 3 received only 40 pounds of nitrogen. Field plats under treatment No. 3 received nothing at the second application. These changes were made because the addition of phosphorus gave no effects and it was desirable to study the residual effects of trash on nitrification and yield.

The applications of trash and fertilizer to the controlled plats were made by chopping the trash into 2-inch lengths, spreading it evenly over the surface of the plats, and then sprinkling the fertilizer over the trash. The whole mixture was carefully spaded into the soil to a depth of 5 inches. Samples were taken to a depth of 6 inches with a sampling tube.

Nitrates were determined on the fresh sample by the phenoldisulfonic acid method. Total nitrogen was determined by the Gunning-Hibbard method. Ammonia was determined by displacement with 0.5 N potassium chloride solution which contained 0.15% copper sulfate and by subsequent distillation with magnesium oxide, as outlined by Bengtsson (2).

Total carbon was determined by the dry combustion method of Winters and Smith (18).

Ether extract was obtained by extracting the oven-dried material in Soxhlet's for 8 hours. Fifty-gram samples of the soil material were used. Alcohol extract was determined on the material after the ether extraction by treating it in Soxhlet's for 8 hours with 95% alcohol. The extract was dried and weighed as in an ether extraction.

Lignin, lignin-humus, and lignin carbon were determined on the material after being extracted with ether and alcohol by a combination of Dore's method (5) and the method of Schwalbe (14).

Reducing sugars were determined on the carbohydrates put in solution and hydrolized as in the treatment for the isolation of the lignin fraction. The iron, aluminum, and manganese were precipitated from the filtrate of the lignin residue in two steps by use of sodium carbonate and a dilute solution of sodium hydroxide. Then total reducing sugars were determined as anhydrous dextrose on the clear, slightly alkaline filtrate by the method of Lane and Eynon (10)[4]

Available phosphorus was determined by the modification of the Deniges colorimetric method for phosphorus as proposed by Truog (15).

Nitrogen-fixing capacity was estimated by direct inoculation of a silica gel medium with the soil according to Winogradsky (17).

EXPERIMENTAL RESULTS

The composition of cane trash varies slightly among the different varieties, but it changes to a greater extent according to the time of harvest and to the length of time it remains in the field after harvest. The nitrogen-carbon ratio of fresh trash immediately after an early harvest of the variety P.O.J. 213 is 1:51. The nitrogen-carbon ratio of the same material after lying on the surface of the field for 3 months is 1:58. This change is caused largely by the loss of the water-soluble substances. The composition of a representative sample of

[4]A detailed and critical description of the methods as modified by the author for the determination of lignin and reducing sugars has been published in Soil Science, 34: 19–23, 1932.

fresh trash from P.O.J. 213 is given in Table 1. In the same table the composition of the residue of the trash that had been put down in rows under a corn crop is given. The rows were opened up with a lister and the furrows filled with trash. Then the trash was bedded on and corn planted on the beds. By this procedure the trash was covered more than 5 inches deep and did not seriously interfere with the cultivation of the crop. A very large sample of this residual trash was taken from four plats after the corn was harvested. It will be noted that the sample was very high in ash which was due to the fact that it was necessary to take considerable of the mineral soil material with the sample. On the basis of total organic material in the sample, the sample contained 2.28% nitrogen, 48.3% carbon, and 40.1% lignin-humus. The analysis indicates that on a percentage basis there is a tendency for the lignin to accumulate as lignin-humus when the material is buried below the surface 5 inches of soil.

TABLE 1.—*Composition of fresh field trash and of trash that had been plowed under on March 10 before planting corn and sampled on October 27 after the corn had been harvested.*

	Fresh trash %	Trash plowed under crop %
Moisture*	70.55	----
Ash	9.92	66.77
Reducing sugars determined as glucose, calculated to cellulose	53.15	10.13
Lignin (62.8% C)	13.23	----
Lignin-humus (53.7% C)	----	13.32
Alcohol extract	9.51	0.59
Ether extract	2.57	0.30
Protein calculated from total N	5.13	4.75
Total organic matter accounted for	92.80	87.15
Total C	41.95	16.04
Total N	0.82	0.76
N in lignin fraction	0.28	0.37
Reducing sugars in alcohol extract	4.41	0.00
Ratio of N to C	1:51.1	1:21.2

*Moisture calculated on basis of moist field weight; other determinations on the oven-dry basis.

The very low total organic matter content and lignin-humus content of cane soils show that lignin does not accumulate to any great extent in the surface of mineral soils in the cane belt. The work of Phillips, Weihe, and Smith (13) shows that under suitable conditions the rate of decomposition of lignin may be as great as that of cellulose. It has been found in the determination of lignin-humus on the soils from check plats that the protein associated with lignin-humus is very resistant to hydrolysis. Approximately 50.5% of

the total nitrogen of the soil is associated with the lignin-humus fraction. This stable nature of the greater portion of the soil protein was noted by Jodidi (9). By comparing the analyses of fresh trash and buried trash (Table 1) it will be seen that the nitrogen fraction tends to accumulate at about the same relative rate as the lignin-humus fraction under the conditions of the subsurface soil. In the surface soil (Tables 2 and 3) the lignin-humus fraction disappears faster than the nitrogen fraction.

The results given in Table 2 show that the addition of ammonium sulfate increased the rate of decomposition of the cane trash in the earlier stages. After the August sampling the percentage of total carbon in the soil was higher in the plats that had received nitrogen in addition to trash, although the nitrogen-carbon ratios were the same. This is further proof of the fact that the addition of nitrogen to material of wide nitrogen-carbon ratio increases the amount of organic matter of a permanent nature that can remain in a soil under aerobic conditions. The trash applied on March 10 was moist field trash that had lain on the surface since harvest. The moisture content varied from 40 to 50%. The total nitrogen, total carbon, and lignin (63.5% carbon) on the dry basis were 0.71%, 41.3%, and 19.5% respectively. The soil which had been treated with trash had a volume weight of 1.21. A truly representative sample of the soil just after the addition of the trash should have shown an increase in the nitrogen and carbon contents of the soil of 0.005% and 0.30%, respectively. An examination of the results for April and May indicates that there was a tendency in sampling to get more trash than was representative of the field conditions. This was due to the fact that in sampling undecomposed trash in a loose soil there is a tendency for the resistant trash to cause the soil to push ahead of the sampling tube and thus make the the sample appear to come from a slighlty greater depth than it actually does.

The carbohydrate content of the soil (Table 2) was estimated by the formula $1.72\ C - (6.25\ N + 1.85 \text{ lignin } C) = \text{Carbohydrates}$, in which C is the total of carbon content, N the total nitrogen content and lignin C the lignin-humus carbon content. The formula is based on the conditions that 58% of the soil organic matter is carbon (16), that 16% of the soil protein is nitrogen, that 54% of lignin-humus is carbon, and that practically all of the soil organic matter can be found in the nitrogen lignin-humus, and carbohydrate fractions. Results obtained from the use of this formula are in fair agreement with the carbohydrates determined as reducing sugars. But it was found

TABLE 2.—*Chemical changes in the surface soil of bare controlled plats after the first addition of trash and fertilizer on March 10, 1930.**

Treatment No.	Total N %	Organic C %	N:C	Lignin C %	Carbohydrates, calculated, %	NO_3-N, p. p. m.		Available P, p.p.m.	
						Apr. 1	Apr. 22	Apr. 1	Apr. 22
				April 22, 1930					
1	0.108	1.11	1:10.3	0.52	0.27	2.8	5.8	88	86
2	0.121	1.32	1:10.9	0.61	0.36	6.4	18.7	116	102
3	0.123	1.40	1:11.4	0.62	0.49	6.3	18.7	111	91
4	0.120	1.39	1:11.6	0.65	0.44	6.9	8.6	103	86
5	0.117	1.39	1:11.9	0.66	0.44	0.0	0.0	107	87
				May 26, 1930					
						May 26	June 28	May 26	
1	0.109	1.12	1:10.3	0.53	0.27	2.3	9.4	83	
2	0.117	1.33	1:11.4	0.62	0.41	4.9	18.0	94	
3	0.120	1.41	1:11.8	0.66	0.46	5.5	17.5	92	
4	0.116	1.36	1:11.7	0.64	0.43	2.1	15.3	91	
5	0.113	1.39	1:12.3	0.64	0.50	1.3	10.0	92	
				August 19, 1930					
						Aug. 19	Sept 13	Aug. 19	
1	0.109	1.09	1:10.0	0.49	0.29	4.6	5.8	89	
2	0.121	1.28	1:10.6	0.60	0.33	7.2	6.4	97	
3	0.117	1.22	1:10.5	0.55	0.35	5.3	6.6	96	
4	0.115	1.21	1:10.5	0.56	0.32	4.2	6.9	94	
5	0.113	1.18	1:10.5	0.55	0.30	3.7	4.2	93	
				October 27, 1930					
						Oct. 20	Oct. 27	Oct. 27	
1	0.105	1.07	1:10.2	0.49	0.28	1.6	2.3	85	
2	0.112	1.17	1:10.4	0.53	0.33	2.0	2.6	86	
3	0.111	1.16	1:10.4	0.53	0.32	2.7	2.1	86	
4	0.110	1.17	1:10.6	0.54	0.32	2.2	2.4	85	
5	0.109	1.14	1:10.4	0.53	0.30	2.5	2.1	85	

*Results are on the basis of dry soil.

later that the reason for this is that the use of the factor 1.72 introduces a low result that is compensated for by the low results of the proximate method of analysis. The carbon content of the soil organic matter is nearer 51% than 58% and approximately 90% of the soil organic matter was accounted for by the method of analysis used.

The availability of phosphorus was increased by the addition of the trash to the soil (Table 2). This increase in availability of phos-

phorus was most marked in the earlier stages of decomposition and disappeared as the nitrogen-carbon ratios of the soils of trash-treated plats narrowed to that of the checks. The greater availability of phosphorus in the plats receiving ammonium sulfate was probably due to a greater production of carbon dioxide, for the untreated soil has a pH of 6.9 and the reaction of the soil was not appreciably changed by the treatments of trash and ammonium sulfate. Even after the second application, the lowest reaction observed was pH 6.7. Tests for acidity were made on air-dry soil.

The composition of the fresh trash used at the second application is given in Table 1. Changes in the content of reducing sugars following the second application (Table 3) indicate that the addition of nitrogen tends to increase the rate of decomposition of the carbohydrate fraction of the trash.

There was a very slow decomposition of the lignin-humus fraction during winter and spring, but a marked decrease in the lignin-humus content occurred in summer. A part of this decrease in lignin-humus may have been due to a decrease in the production of humus from other materials by certain fungi (8) as the easily decomposable materials disappeared.

It is very obvious from the total nitrogen and carbon contents of the soil from the treated plats that the trash which was added in October had decomposed at the end of the experiment in August to practically the same nitrogen-carbon ratio as that of the organic matter of the soil from the check plats at the time of the application of the trash. The addition of trash increased the soil organic matter, with the greatest increase occurring from the treatments of trash plus inorganic nitrogen. Since the decomposition and synthetic processes in the soil tend to maintain the nitrogen-carbon ratio of the soil organic matter at a constant value, 1:10, the increase of the soil organic matter was proportional to the nitrogen present in the trash and added with it.

The soil gained in nitrogen from the addition of trash. There was a net gain in the surface soil of approximately 75 pounds of nitrogen per acre above all the field losses. By assuming that the leaching losses from the plats treated with trash only were not greater than those from the check plats, which is an assumption that a comparison of the nitrate accumulation in the differently treated plats indicates to be a fact, the increase in soil nitrogen from the two applications of trash was equal to 130 pounds of nitrogen per acre of surface soil or within the limits of experimental error the increase in soil nitrogen

was equivalent to nitrogen content of the trash added. The nitrogen losses from the surface soil of the check plats were equal to 55 pounds per acre. These results indicate that the surface soil did not gain in nitrogen above what was added in trash or fertilizer, but this does not preclude the fact that some fixation of nitrogen may have taken place, since the conditions of the experiment did not permit of the measurement of the changes in the nitrogen of the subsoil or losses of nitrogen through drainage water.

A very small portion of the soil organic matter is soluble in ether or alcohol. Data in Table 3 show that, although the addition of trash increased the ether and alcohol extracts of the soil, there was no significant tendency for these substances to accumulate in the soil.

Data in Tables 2 and 3 and in Fig. 1 on nitrification and accumulation of nitrates show that the addition of cane trash caused a marked depression in the accumulation of nitrates in the soil. This depression lasted for 3 months following the application of trash on March 10. The lowering of nitrates in the soil was not so marked following the second application of trash on October 27. Seasonal effects in the fall tend (Table 4) to reduce the rate of nitrification, so that it was more difficult to determine significant differences between fall treatments than between spring treatments.

A condition of great agronomic importance is shown in Table 3 and Fig. 1. The trash that had been mixed with the surface soil in the fall had ceased to lower the available soil nitrogen by April. The concentration of ammonia was higher in the soil of the trash-treated plats than in that of the checks, while the nitrate accumulation was at practically the same level as that of the checks. Ammonia accumulates to a much greater extent than nitrates during the winter and spring months.

Fig. 1 also shows that the residues from trash nitrify slowly but steadily. It will be noted from Table 4 that the quick drops in nitrate accumulation are due to rains leaching out the nitrates. The tendency for the nitrates to increase after rains is proportional to the rate of nitrification. To get a more definite notion of the relative rates of the nitrification of trash residues and inorganic fertilizer, the plats under treatment No. 3 received no trash and only 40 pounds per acre of nitrogen as ammonium sulfate at the second application. Results in Table 3 show that half of the inorganic nitrogen was nitrified within the first week after application and that the nitrates disappeared through the winter months. Data on treatment No. 4 in Table 3 show that, although the addition of 40 pounds of nitrogen as ammonium

TABLE 3.—*Chemical changes in the surface soil of bare controlled plats after the second addition of trash and fertilizer on October 27, 1930.**

Treatment No.	Total N %	Organic C %	N:C	Lignin C %	Ether extract %	Alcohol extract %	Reducing sugars %	NH_3-N, p. p. m.	NO_3-N, p. p. m	
November 25, 1930										
									Nov. 5	Nov. 25
1	0.1054	1.062	1:10.1	0.488	0.011	0.026	0.307	7.0	1.1	0.4
2	0.1200	1.384	1:11.5	0.613	0.019	0.031	0.513	16.1	11.6	2.8
3†	0.1128	1.175	1:10.4	0.529	0.020	0.027	0.343	15.4	14.2	3.8
4	0.1157	1.339	1:11.6	0.626	0.022	0.034	0.526	11.2	0.8	0.9
5	0.1114	1.302	1:11.7	0.612	0.027	0.027	0.512	7.0	0.7	0.2
January 22, 1931										
1	0.1060	1.058	1:10.0	0.483	0.013	0.024	0.306	9.8	2.41‡	—
2	0.1188	1.311	1:11.0	0.575	0.016	0.034	0.465	14.0	2.5‡	—
3	0.1118	1.135	1:10.2	0.510	0.016	0.027	0.328	14.6	3.1‡	—
4	0.1162	1.304	1:11.2	0.597	0.019	0.033	0.491	12.6	1.8‡	—
5	0.1126	1.306	1:11.6	0.612	0.021	0.025	0.508	9.2	1.7‡	—
March 11, 1931										
									Mar. 17	Apr. 10
1	0.1060	1.063	1:10.0	0.490	0.016	0.026	0.278	11.6	0.5	1.2
2	0.1155	1.229	1:10.6	0.547	0.017	0.035	0.401	13.1	0.8	2.6
3	0.1110	1.123	1:10.1	0.513	0.014	0.030	0.304	10.9	0.7	2.3
4	0.1157	1.271	1:11.0	0.574	0.017	0.029	0.413	10.2	0.7	1.9
5	0.1142	1.294	1:11.3	0.597	0.018	0.033	0.453	10.1	0.6	1.1

									Apr. 26	May 27
					April 26, 1931					
1	0.1055	1.045	1: 9.9	0.483	0.008	0.030	0.283	9.8	1.8	8.4
2	0.1212	1.269	1:10.5	0.572	0.008	0.044	0.409	16.1	2.9	14.1
3	0.1135	1.132	1:10.0	0.497	0.007	0.037	0.309	11.9	2.5	10.5
4	0.1182	1.281	1:10.8	0.575	0.013	0.039	0.422	16.1	2.3	9.0
5	0.1175	1.334	1:11.3	0.610	0.011	0.037	0.480	13.3	1.5	6.8
					June 12, 1931					
1	0.1040	1.044	1:10.0	0.464	0.009	0.032	0.275	6.3	6.6§	—
2	0.1173	1.254	1:10.7	0.579	0.008	0.038	0.371	8.4	11.2§	—
3	0.1098	1.124	1:10.1	0.511	0.008	0.033	0.306	9.1	7.2§	—
4	0.1163	1.233	1:10.6	0.581	0.009	0.041	0.388	9.1	7.6§	—
5	0.1140	1.226	1:10.8	0.572	0.008	0.033	0.402	8.4	5.9§	—
					August 1, 1931					
1	0.1049	1.048	1:10.0	0.460	0.008	0.031	0.271	3.5	5.3‖	—
2	0.1159	1.180	1:10.2	0.501	0.010	0.040	0.324	6.2	9.0‖	—
3	0.1085	1.078	1: 9.9	0.482	0.009	0.032	0.289	5.6	9.0‖	—
4	0.1129	1.164	1:10.3	0.521	0.009	0.039	0.324	6.5	8.2‖	—
5	0.1119	1.153	1:10.3	0.520	0.010	0.034	0.338	5.2	5.1‖	—

*Results are on the basis of dry soil.
†Plats under treatment No. 3 received only 40 pounds of ammonium sulfate at the second application.
‡January 31, 1931.
§June 12, 1931.
‖August 1, 1931.

sulfate with the trash did not increase the nitrate accumulation until spring, there was an increase in the available nitrogen at a time when the crop could benefit most from its use. It can be seen from Fig. 1 that the addition of 80 pounds of nitrogen to 12 tons of trash immediately

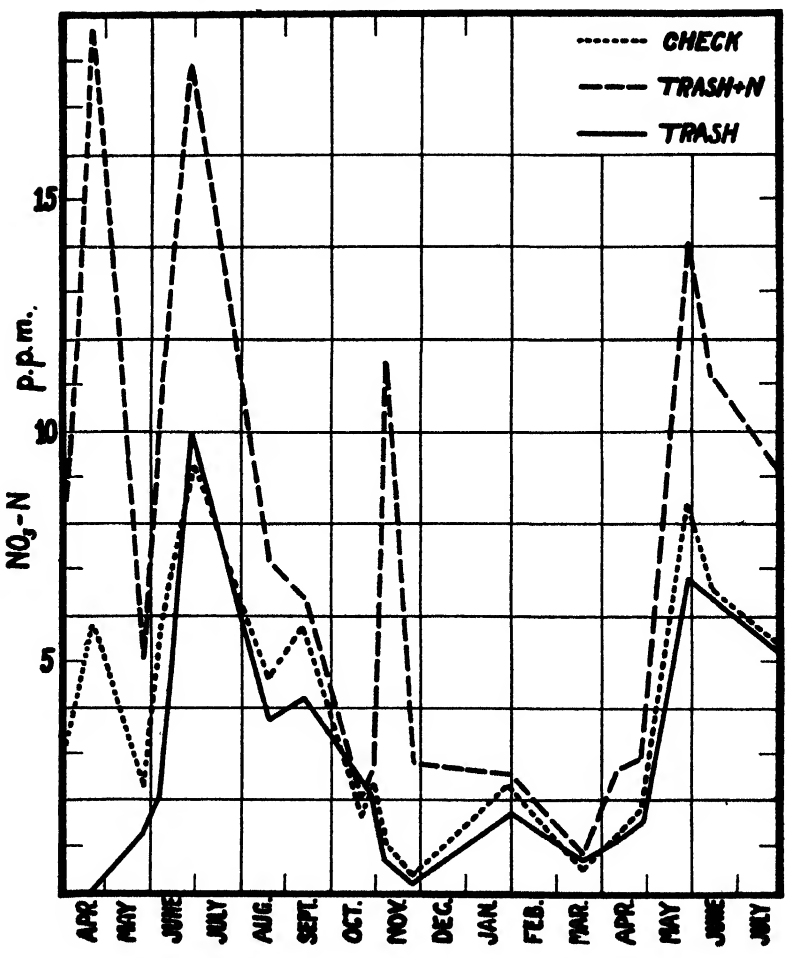

FIG. 1.—The effect of no treatment, of 12 tons of trash and 80 pounds of nitrogen per acre, and of 12 tons of trash per acre on nitrification and nitrate accumulation in the controlled plats. Note that the second application was made on October 27.

increases the nitrate content more than 10 p.p.m. above that of the checks. This indicates that approximately 60 pounds of nitrogen would have taken care of the nitrate depression of 12 tons of trash per acre.

TABLE 4.—*Moisture in check soil at time of sampling,* rainfall, and atmospheric temperature for periods preceding sampling.*

Date	Moisture %	Rainfall for preceding 2 weeks, inches	Rainfall between samples, inches	Average atmospheric temperature for preceding 2 weeks, °F
April 1, 1930.......	30.2	1.38	2.00	56.3
April 22, 1930......	24.4	1.40	2.10	65.7
May 26, 1930.	24.9	5.55	5.57	74.5
June 6, 1930.......	20.5	0.46	0.46	74.6
June 28, 1930.......	16.5	0.00	0.00	82.4
July 19, 1930.......	12.7	2.31	8.70	84.7
September 13, 1930..	26.6	2.00	3.89	81.6
October 20, 1930 ..	25.5	2.05	7.61	72.0
October 27, 1930....	25.2	0.39	0.00	63.7
November 5, 1930...	27.6	0.59	9.59	57.4
November 25, 1930..	28.0	5.08	5.08	63.1
January 31, 1931....	24.5	0.00	11.44	50.4
March 17, 1931...	25.6	1.08	5.85	54.5
April 10, 1931......	24.2	2.76	4.34	56.6
April 26, 1931......	24.8	0.09	0.09	66.5
May 27, 1931	20.2	1.72	3.81	70.0
June 12, 1931. ...	22.3	0.57	0.57	74.8
August 1, 1931.....	20.5	1.12	8.90	81.5

*The soil had a moisture-holding capacity of 50.4%.

Since the data show that there is considerable loss of nitrogen from the surface soil during winter and spring months and that the trash will decompose sufficiently without the addition of nitrogen if applied early, chopped and mixed with the surface soil, it seems that it would be more profitable to apply the nitrogen in the spring. However, under conditions where it is not possible to make an early application of trash, the addition of 5 pounds of nitrogen per ton of trash will prevent a lowering of the available soil nitrogen.

Studies on the nitrogen-fixing capacity of the soil show that both the treated and untreated soil contained an abundant nitrogen-fixing flora which gave under laboratory tests active to very active nitrogen-fixing capacities. Data in Table 5 show that there was no significant difference between the treatments in their effect on the nitrogen-fixing capacity as measured by the method of Winogradsky (17). Abbott (1) found in a study of non-symbiotic nitrogen fixation on the same type of soil used in this experiment that Azotobacter were plentiful and by the use of a different medium obtained results somewhat lower than the values given here. The data from the controlled plats do not establish any gain from the fixation of nitrogen in the field through the use of cane trash, but it is highly probable that a considerable fixation was covered up by a still higher leaching loss from the bare surface soil.

The effect of trash and fertilizer on the yield of corn in field plats is shown in Table 6. The trash, which was not chopped as in the controlled treatments, and fertilizer were put in rows that had been opened by a lister. Then the trash was bedded on and corn planted on the beds. In the fall application preceding the 1931 crop, the trash and fertilizer were very lightly covered in the fall and bedded on in the spring before planting.

TABLE 5.—*Nitrogen fixing capacity in mg of N fixed per gram of mannitol on a selective silica gel medium that had been inoculated with soil from the plats under treatment.*

Treatment	April 1, 1930	April 22, 1930	May 26, 1930
1	8.5	9.1	9.5
2	8.6	9.6	10.0
3	10.0	9.9	8.3
4	8.6	9.3	9.6
5	9 7	8.3	7.9

During the first part of June 1930 the young corn on the plats which had received trash only appeared decidedly less vigorous in growth and more yellowish in color than the corn on the check plats. But by July, the crop on the trash-treated plats had improved markedly. The better growth of corn on the plats which had received trash plus nitrogen indicated that the added nitrogen tended to correct for the depressive effect of the trash.

The field observations on the 1931 crop show that a depressive effect from the trash was apparent on the early growth of corn and that the crop on the trash plats improved as temperature, drainage, and aeration increased. Where 80 pounds of nitrogen per acre had been added to the trash, the depressive effect was apparently corrected on the better drained plats. There was no nitrate accumulation in the soil of the field plats in early spring. Tests made in February and March failed to show more than 1.0 p.p.m. under any of the treatments.

Data given in Table 6 show that the late applications of trash reduced the yield of corn in 1930. The early application of trash increased the yield of corn in 1931, but some of this increase was due to the residual effect from the first application. Additions of nitrogen with the trash increased the yield. There was a marked increase in the yield of corn in 1931 from the residues of the first application of 80 pounds of nitrogen and 12 tons of trash per acre. Better yields from the use of trash could be expected on crops that have a later and longer growing season than corn.

TABLE 6.—*The effect of trash and fertilizer on the yield of corn in bushels per acre on 1/20 acre field plats.*

Treatment No.	1930	1931
1	32.8	33.0
2	36.2	44.6
3	36.2	39.4
4	38.0	38.4
5	27.4	37.1

*Plats under treatment No. 3 received no trash or fertilizer at the second application. The gain in 1931 was due to the residues from the first treatment.

SUMMARY

Cane trash that was chopped and turned into the surface soil on March 10 caused a marked lowering of the nitrate nitrogen in the soil. The depressive effect lasted for 3 months. Cane trash that was applied in the same manner on October 27 had decomposed sufficiently by the following April to have ceased to lower the available soil nitrogen, both ammonia and nitrate.

By the addition of inorganic nitrogen with the cane trash at the rate of 5 pounds of nitrogen per ton of fresh field trash and the incorporation of the mixture within the surface 5 inches of soil, the rate of decomposition will be increased and the presence of available soil nitrogen insured. Since the nitrate nitrogen disappears from the surface soil during the winter and spring, an early application of the trash alone with the supplemental nitrogen being added in the spring directly ahead of the crop would prove the more practical method for the use of trash.

The application of cane trash to the soil increased the soil nitrogen and organic matter. The gain in the soil nitrogen from the use of trash was, within the limit of experimental error, equivalent to the nitrogen content of the trash.

The resultant decomposition following the application of trash increased the availability of phosphorus 15 to 20 pounds per acre during the earlier stages of decomposition.

After the organic material had decomposed to the nitrogen-carbon ratio of the untreated soil, 14% of the soil organic matter still remained as carbohydrates. The fact that it is possible to estimate only the microbial carbohydrate material puts somewhat of a limit on the disappearance of carbohydrates as a measure of the rate of decomposition.

The lignin fraction of cane trash undergoes slow decomposition and tends to accumulate in the soil when the trash is buried, but when the trash is turned into the surface soil there is no excessive accumu-

lation from lignin. True lignin of the plant material gradually changed to lignin-humus material which had a much lower carbon content than the original lignin. Lignin-humus decomposes slowly in winter and spring but very appreciably in summer.

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RELATION OF CALCIUM AND MAGNESIUM TO THE GROWTH AND QUALITY OF TOBACCO[1]

J. E. McMurtrey, Jr.[2]

It has been generally considered that nitrogen, phosphorus, and potassium constitute a complete fertilizer. However, due to the complex materials previously used in their manufacture, the so-called complete fertilizers have contained considerable quantities of chemical elements essential to plant growth other than the three mentioned. On the other hand, there is a definite trend in the fertilizer industry, largely due to economic demands, toward the use of relatively pure chemicals intended to furnish in highly concentrated form and comparatively free from "filler" or supposedly inert material, the three elements nitrogen, phosphorus, and potassium. Mixtures of ammonium nitrate and potassium phosphate or potassium nitrate and ammonium phosphate are examples of this type of fertilizer. Recent investigations have demonstrated that such mixtures do not give satisfactory results on all soils and under all conditions when compared with the old type mixtures.

It becomes desirable, therefore, to determine what are the factors involved. Some workers have reported that the unfavorable results were possibly due to concentration of soluble salts resulting in injury to roots of the crops grown. Such a conclusion hardly appears to be justified provided there is a reasonably even distribution of the fertilizer, because the high analysis materials used in such mixtures actually require less soluble salts per acre than most of the low grade fertilizer materials in order to supply the same amount of plant food. On the contrary, in the case of results of experiments with tobacco, (2),[3] the chief difficulty was that certain elements were absent from the mixture. It did not appear that the elements nitrogen, phosphorus, and potassium failed to function normally in the concentrated forms used, but rather it seemed that in the soils in question there was a shortage of calcium and magnesium. In an earlier paper,

[1]Contribution from the Division of Tobacco and Plant Nutrition, Bureau Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also read as a part of the symposium on "The Relation of Calcium and Magnesium Compounds to Soil Conditions and Plant Growth" at the meeting of the Society held in Chicago, Ill., Nov. 20, 1931. Received for publication January 16, 1932.

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[3]Reference by number is to "Literature Citted," p. 715.

Garner, *et al.* (1) pointed out the necessity for including magnesium in the fertilizer mixture. Detailed yield data have been published (4), showing the beneficial effects of including magnesium in the fertilizer. Murwin (5) has given the effects of magnesium on yield and quality of the cigar type of tobacco. For details of the experimental procedure those interested are referred to the above articles as the basis of the present paper.

CALCIUM REQUIREMENTS

It has been the general assumption that all agricultural soils contain sufficient calcium for the nutrition of most plants and that this element only needs to be added in the hydrate or carbonate form to improve the soil reaction. The abundant calcium in the sulfate and phosphate compounds of superphosphate has been considered as having no direct fertilizer value, and this material which is used almost universally has been regarded merely as a desirable source of phosphorus. That such assumptions are not justified, at least in the case of tobacco, will be shown in the following discussion. The ability of the calcium ion to antagonize or render harmless the growth of other objectionable ions is well recognized. This antagonistic action of calcium appears to be one of the chief functions of this element with light as well as with heavy rates of application. The antagonistic action of calcium is possibly one of the properties upon which the extensive use of this element in the hydrate or carbonate form to correct the so-called soil acidity has been founded In view of the fact that the tobacco plant usually does not thrive in a neutral or alkaline soil due to black root-rot caused by *Thielavia basicola*, the indiscriminate use of these compounds in the quantities usually recommended to correct soil acidity is not desirable. Also, with some types of tobacco, the ability of these forms of calcium when used freely to render available for growth excessive quantities of nitrogen is objectionable.

The quantity of calcium necessary for the normal nutrition of the tobacco plant will necessarily vary with the conditions. In the last analysis it will be determined by the ability of the plant to absorb sufficient for its needs. In the studies made so far it appears that the quantity of calcium necessary for normal growth of the leaves must be in excess of 1% of their dry weight. In trials made at Upper Marlboro, Maryland, on soils of the Collington series after 1 or 2 years cropping to tobacco, the native supply of this element was found to be inadequate for normal growth. However, where only

35 pounds per acre of calcium were supplied in the form of the nitrate, sulphate, carbonate, or phosphate, the growth was normal. The phosphate, however, appeared to give the best growth. The rates of application of nitrogen, phosphoric acid, and potash were 40, 64, and 80 pounds per acre, respectively, in this series. In another series where the nitrogen rate was double this quantity and where the calcium was derived from nitrate, it was noted during the past season that heavier rates of calcium were necessary to produce normal growth. It is possible that the heavier rates of nitrogen used on this series have stimulated the plants to greater growth thereby resulting in the exhaustion of the soil reserves of this element. There is also another possibility in that during the past season the rainfall was excessive and may have leached out the readily soluble calcium nitrate which was applied before the crop was planted.

SYMPTOMS OF CALCIUM DEFICIENCY

When the supply of calcium in the soil is insufficient and it is not supplied in the fertilizer, the tobacco plant exhibits characteristic abnormalities in growth. These abnormalities are influenced by other ions present under the conditions. Magnesium in quantities which in the presence of calcium would produce normal growth appears to become toxic when calcium is lacking, producing abnormalities in leaf and terminal bud development which for all practical purposes may be considered as typical of calcium deficiency. The first sign of calcium deficiency is a peculiar hooking downward at their tips of the young leaves making up the bud. This is followed by the death of the young leaves, characteristically at their tips and margins and if growth later takes place the tips and portions of the margins are missing. Such a condition results in the upper leaves showing a cut out appearance, as illustrated in Fig 1. The plant as a whole exhibits an abnormally dark green color and some thickening of the leaves as the result of the topping effect due to death of the terminal bud. In the later stages all terminal growth is stopped and some necrotic spots and chlorosis may develop on the older leaves, though this is not always the case. If development of lateral shoots or suckers begins in the axils of the leaves, these shoots tend immediately to develop the above-described effects and die back. These are the effects which are typical in water and sand cultures and have been observed under field conditions on some soils.

There is another type of injury resulting from a shortage of calcium which appears to be associated with an acid reaction of the soil

containing manganese. Tobacco plants grown under these conditions usually show a chlorosis of the young leaves of the bud followed by more or less spotting of leaves. This condition has been reproduced by adding excess manganese to the soil in pots in which tobacco plants were being grown. Also, it has been observed under field conditions where ammonium sulfate was used as the source of nitrogen over a period of years. Where dolomitic limestone was used at the rate of 1 ton per acre on the same treatment the condition did not occur.

FIG. 1.—Individual tobacco plant illustrating abnormalities in leaf development which resulted from an insufficient supply of calcium.

EFFECTS OF CALCIUM ON YIELD AND QUALITY

The present discussion is based rather upon the presence or absence of calcium in its effects upon growth than upon a study of exact rates at which this element should be supplied. Where a certain area of soil was cropped continuously to tobacco, it showed little or no reduction in yield and quality for the first year or so when calcium was omitted from the fertilizer. Thereafter, however, it may be said

FIG. 2.—A, plat of tobacco (four rows) grown with a fertilizer mixture which did not supply calcium. B, tobacco (four rows) grown on an adjacent plat which was fertilized with a mixture furnishing calcium. Scale in feet.

that no crop at all was produced (Fig. 2) when this element was omitted. The quality of the cured leaf was necessarily very poor due to the physiological disturbance to growth resulting from the shortage of this element which produced leaf malformations, thickening, premature death of the terminal bud, and associated phenomena.

MAGNESIUM REQUIREMENTS

The literature is so filled with references to the possible toxicity of the magnesium ion that until a few years ago it was not recognized that this element is not furnished in sufficient amounts by all soils to produce normal growth. The first paper giving proof of magnesium deficiency under field conditions was published in 1923. At that time it was not recognized that deficiency of this element is so extensive as has since been proved to be the case. Magnesium deficiency has been reported on several soil types of the coastal plain area and has been found to occur with tobacco, corn, potatoes, soybeans, and cotton grown on these soils.

It has been noted from the beginning that the requirements for magnesium are decidedly influenced by the amount of rainfall during the growing season. The name sand drown, which was first applied by growers to this deficiency in tobacco, actually suggests a true picture of the conditions with which it is commonly associated, that is, deep sandy soils and excessive rainfall. The quantity of magnesium which must be present in the tissues to prevent deficiency of this element for growth has been found to be around 0.25% of the dry weight of the leaves. On some soils and with certain types of tobacco the actual quantity of magnesium that has been supplied to prevent symptoms of deficiency is 12 pounds per acre when applied as the sulfate or chloride. On the other hand, five times this amount has not been harmful when as much as 35 pounds of calcium was supplied in the fertilizer. The crude potash salts containing magnesium, such as some forms of kainit and sulfate of potash-magnesia, have also been found to be effective in supplying any deficiency of magnesium. However, it is not desirable to use kainit on tobacco due to its chlorine content. Organic materials of plant or animal origin, such as cottonseed meal or barnyard manure, when supplied in sufficient quantities, have been effective in preventing any deficiency symptoms of this element in tobacco.

Dolomitic limestone which is relatively insoluble as a rule has been effective in correcting any effects of shortage of this element when it is applied at the rate of 1,000 pounds per acre. The quantity of this

material required will also be influenced by the fineness to which it is ground. Dolomitic limestone has not proved to be an ideal source of magnesium under all conditions since in some cases the rates at which it is necessary to supply this material change the soil reaction to such an extent that black root-rot becomes a problem. It was also noted during the past season for the first time that this material when coarsely ground did not under all conditions correct the deficiency when supplied at the rate of 1,000 pounds per acre. This may have been due to the peculiar season which, as previously stated, was one of excessive rainfall. There appears to be no toxicity from dolomitic limestone since it has been found possible to grow tobacco plants in ground dolomite as the culture medium provided the other nutrients are supplied.

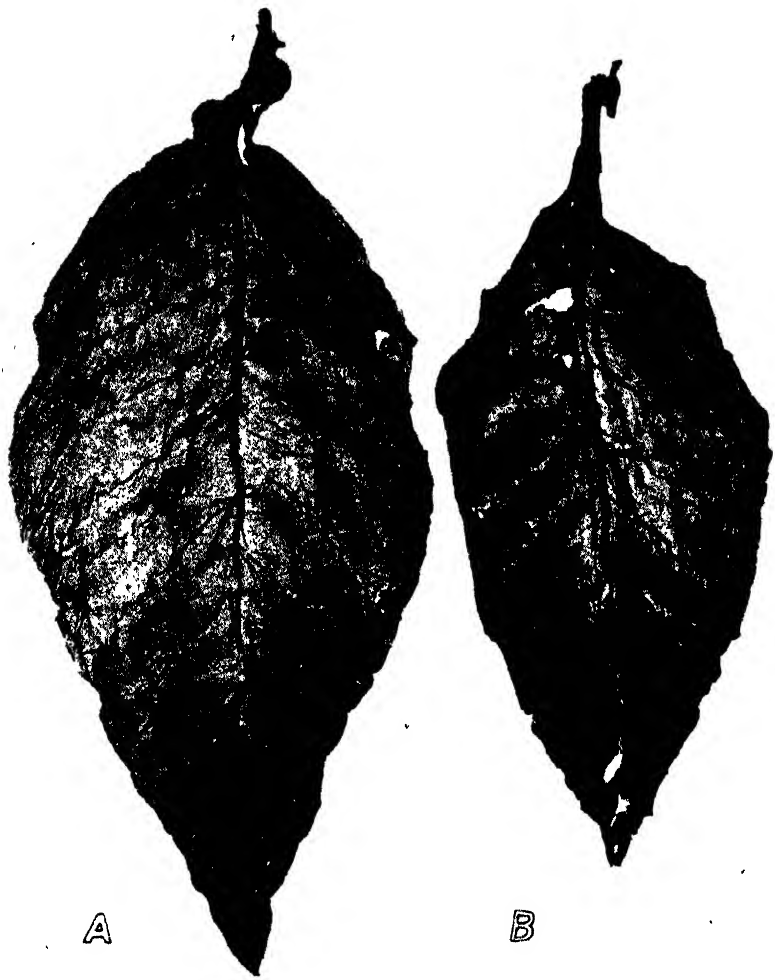
SYMPTOMS OF MAGNESIUM DEFICIENCY

When there is a shortage of magnesium in the soil and when this element is not supplied in the fertilizer, the tobacco plant grown on such soil exhibits characteristic deficiency symptoms. Since this element is a constituent of chlorophyll the green pigments break down when the supply is insufficient as previously illustrated in this JOURNAL (3). Typically, this loss of green color develops first on the lower leaves of the individual plant, usually beginning at the tip and progressing inwardly on the leaf toward its base, along the margins and between the veins. The chlorosis advances progressively from the lower leaves of the plant upward. The first sign of this deficiency is a pale green or almost white color of the tip of the leaf, but in later stages only the principal veins will retain the normal green color, while in extreme cases even these lose most of the green appearance and the entire leaf area of the plant may become almost white. Leaves showing the most extreme symptoms of magnesium deficiency rarely dry or "fire" prematurely and this serves to distinguish the condition from a deficiency of nitrogen or potash which is characterized by more or less firing.

EFFECTS OF MAGNESIUM ON YIELDS AND QUALITY

If the growing tobacco plant exhibits the symptoms previously described, the yield is reduced and the quality of the crop is lowered. The reduction in yield will vary, depending upon the acuteness of the shortage. In actual trials at Oxford, N. C. (4), it was found over a period of years that where magnesium was deficient the yield was reduced approximately by one-fourth and the gross value per acre by

about one-third. The average value per pound was 3 to 4 cents higher where magnesium was applied compared to where it was omitted. Therefore, it appears that the reduction in quality is more marked



A B

FIG. 3.—Tobacco leaves, flue-cured type, after curing. A, leaf from a plant grown with an adequate supply of magnesium. B, leaf from a plant where the supply of magnesium was deficient for normal growth. Note uniform color of A and discolorations on leaf B.

than the reduction in yield. The reduction in quality is due to the irregular colors, loss in weight, and lack of body and elasticity which result from a shortage of this element. Symptoms in the cured leaf

are more readily recognized in the flue-cured type of tobacco as illustrated in Fig. 3. A yellow color in the cured leaf is of prime importance to quality in this type.

COMPARISON OF DEFICIENCY EFFECTS OF CALCIUM AND MAGNESIUM

The requirements for calcium and magnesium appear to be influenced to a certain extent by each other. In other words, as the supply of one is increased, the need for the other is accentuated. On

FIG. 4.—A, plat of tobacco (four rows) grown with a fertilizer mixture which did not supply calcium and magnesium. B, plat of tobacco (four rows) grown on a nearby plat which was fertilized with a mixture furnishing calcium and magnesium. Scale in feet.

the other hand, it is impossible to obtain normal growth if both are lacking. The quantities actually necessary for normal growth indicate that calcium must be absorbed in much larger quantities than magnesium.

The symptoms of deficiency are decidedly different. A shortage of magnesium results in a typical chlorosis of the lower leaves, indicating that this element is highly mobile in the plant. On the contrary, a shortage of calcium results in characteristic effects on the new growth which in extreme cases lead to the death of the terminal bud, showing that calcium is relatively immobile in the plant.

When both are deficient in the soil and are not supplied in the fertilizer mixture, there is a marked reduction in growth (Fig. 4). This effect is typical of mixtures of potassium nitrate and ammonium phosphate or ammonium nitrate and potassium phosphate when used on such soils. Under these conditions the most apparent symptoms are those which are characteristic of a shortage of magnesium, but the growth is reduced to a much greater extent than if either calcium or magnesium alone were deficient.

SUMMARY

When only nitrogen, phosphorus, and potassium are supplied in the fertilizer on some soils the growth of the tobacco plant exhibits definite pathological symptoms and growth is decidedly reduced. The addition of magnesium results in some increase in growth, but the growth still may be abnormal. This abnormality consists of development of upper leaves of the plant in which the tips and margins are partly missing. This gives these leaves a cut-out appearance. The plant as a whole shows a dark green color and in the later stages the terminal bud dies. This condition is corrected by the addition of calcium and may be considered as typical of calcium deficiency. The addition of calcium alone to the mixture supplying nitrogen, phosphorus, and potassium results in characteristic symptoms of magnesium hunger, which are typified by a breaking down of the chlorophyll. This chlorosis begins on the lower leaves of the plant and at the tips of the affected leaves.

It appears that the leaf tissues should contain more than 1% of calcium to prevent symptoms of its shortage. The requirement for prevention of symptoms of magnesium deficiency is a content of around 0.25% in magnesium in the dry leaf. These requirements have been met by furnishing in suitable forms 35 pounds of calcium and 12 pounds of magnesium per acre on the soils in question. However, when dolomitic limestone was the source of magnesium it was necessary to supply considerably larger quantities. This material has not given satisfactory results with tobacco under all conditions.

Where farm manure and other organic materials of plant or animal origin have been used extensively as fertilizers, a shortage of calcium and magnesium has not been apparent. The extensive use of superphosphate or other calcium phosphates as constituents of standard fertilizer mixtures has avoided any danger of loss of production from acute shortage of the element calcium.

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THE EFFECT OF LIMING SOILS ON THE AVAILABILITY OF MANGANESE AND IRON[1]

L. G. Willis[2]

The availability of plant nutrients is related in a limited sense to the factors governing the solubility and suitability for assimilation of the sources of plant nutrients; but since soil treatments, such as liming, influence the physiological processes of plants as well as the solubility of the nutrients, the effect of liming is properly concerned with the broader aspect of the efficiency of the nutrient elements. A deficiency of any nutrient may therefore result from a reduction in the supply or from the operation of any influence that interferes with normal utilization.

Manganese and iron can be considered true plant nutrients in the sense that they regulate important physiological processes, although there is some evidence that the effect of manganese may be secondary to that of iron. Maze (21)[3] and Gilbert, *et al.* (5) have shown that manganese deficiency can not be corrected by the use of iron, but according to Hopkins (13) the function of manganese may be one of activation of iron in the plant. The hypothesis offered is that iron is reduced in the organism by the process of photosynthesis and that the manganese serves to reoxidize it.

If some other oxidant could serve the same purpose there would be grounds for questioning the essential nature of manganese. No such substitution has been observed. Skinner and Ruprecht (28) have shown that copper sulfate gives very little response on a manganese-deficient soil and Samuel and Piper (26) found that boron, aluminum, zinc, copper, cobalt, nickel, barium, strontium, iodine, and silicon cannot satisfy the requirement for manganese in solution cultures.

The availability of manganese to plants is most obviously governed by the reaction of the soil. McLean and Gilbert (22) report a man-

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[3]Reference by number is to "Literature Cited," p. 724.

ganese-deficiency chlorosis of spring-planted spinach on heavily limed soils having reactions ranging from pH 6.2 to 6.9. A chlorosis of soybeans that was corrected by applications of manganese sulfate was found (28) on some North Carolina Coastal Plain soils at reactions ranging from 6.2 to 7.4.

Mann (19) has shown that the solubility of manganese in water extracts of soils is reduced to extremely low levels by liming, with a virtual minimum concentration reached at pH 5.8 on one soil and 7.0 on another. There may be some significance in the fact that no cases of manganese deficiency have been reported on the latter soil whereas it is commonly found on the former.

In North Carolina, manganese deficiency has only been observed on the heavier soil types, but Zimmerly (31) reports occurrences of a manganese-deficiency chlorosis of spinach on the lighter soils of the Norfolk series. He found, however, that this disease never develops in the fall and winter crops even where the reaction reaches pH 8.0.

The observation that chlorosis occurs typically on heavy or cold or wet soils would suggest a hypothesis that the susceptibility of plants to manganese deficiency is related to limited root development if it were not for the contradictory evidence given by Godden and Grimmett (9) that more manganese was absorbed by plants growing in soil in undrained than in drained pots, and that of Samuel and Piper (26) that more manganese was found in oats growing on strongly alkaline soil that was tightly compacted than on a looser and less alkaline soil. The latter writers note that their observation coincides with one that oats growing on manganese-deficient soils in South Australia are benefited by rolling and offer the suggestion that the oxidation-reduction potential of the soil may be an important property in relation to manganese deficiency. This conclusion is also supported by the observation of Robinson (24) that waterlogging a soil increased the solubility of manganese.

Opposed to the idea that manganese is more available under reducing conditions is the observation of Hudig and Meijer (14) that the gray speck (dry spot) disease of oats which they controlled by fertilization with manganese sulfate and which Samuel and Piper (26) have shown to be symptomatic of manganese deficiency is aggravated by the addition of such reducing substances as cellulose and starch.

Manganese may occur in the soil in primary or secondary mineral forms. The igneous rocks contain very small percentages, but concentrations of the dioxide minerals formed by the oxidation of the carbonate

are common. The dioxide occurs largely in the sand and silt fractions (23), while the divalent form is present as a replaceable base in the clays (18, 26).

The observation that manganese deficiency may occur in soils at pH 6.2 is not compatible on the basis of reaction alone with the data of Carr and Brewer (4) who showed that manganous hydroxide does not begin precipitation below 7.2 and that precipitation is not complete below 8.0. The carbonate is appreciably soluble in carbonated water which is always present in normal soils. It is not improbable, therefore, that the conversion of manganese hydroxide or carbonate to the less soluble higher oxides is essential to the development of manganese deficiency and conversely that the availability of manganese would be increased under reducing conditions.

At very low concentrations of available manganese, plant growth will be influenced by the requirements of the plant, according to the observations of Samuel and Piper (26), who found in water cultures that oats were arrested in their development by a deficiency of manganese at a concentration that permitted the maturation of rye and it is not uncommon to find rye growing normally in fields where oats have failed because of insufficient manganese.

The well-known acidifying effect of sulfate of ammonia has been used in practise as a means of increasing the availability of manganese and applications of sulfur might be used for a similar purpose. Fertilization, except as it might increase the acidity of the soil, appears to depress the assimilation of manganese according to some unpublished data by Herman (10). The differences are not large, but they show that heavy fertilization might seriously affect crops on soils that are limed to the threshold of manganese deficiency.

On the basis of the evidence it appears that soils low in total content of manganese may not support normal growth of crops because of a deficiency of that element if the acidity of these soils is less than pH 6.2. Conditions favorable for oxidation of the manganese to the dioxide may be essential to the occurrence of this deficiency and the severity of the symptoms of deficiency or the hazard to crops will increase with rising pH values.

Other factors involved are the requirements of the crop for manganese and some undetermined properties of the soil which vary with the season and moisture content and the degree of compactness. These may relate to the solubility of manganese as they govern the reaction or the oxidation-reduction equilibrium of the soil, or to the extent of plant root systems, or to other factors affecting assimilation.

Practical means of controlling manganese deficiency in soils subject to this limitation will depend on the type of agriculture practised. On naturally calcareous soils, fertilization with manganese sulfate at rates ranging from 50 to 200 pounds per acre appears to be the only practicable remedy. For soils that are normally acid the restriction of the use of lime to rates that will not reduce the acidity beyond pH 6.4 will satisfy the general requirements. Manganese-deficiency chlorosis has been observed on soils at pH 6.2, but it is probable that these had been limed to higher pH values and that 6.2 is the point of recovery rather than that of development. It is doubtful that a deficiency will occur if the pH value of a soil never exceeds 6.4.

Where crops intolerant of strongly acid soils, such as spinach, lettuce, and table beets, are to be grown, the margin between the maximum acidity tolerated by the crop and the minimum at which manganese is available may be so narrow as to justify on poorly buffered soils more liberal liming and fertilization with manganese In some cases it may be possible to apply manganese sulfate to crops either as a side dressing or as a spray on the leaves after deficiency symptoms are evident and bring about a timely recovery.

The use of manganese as a fertilizer on strongly acid soils is not recommended because of the well-known toxic properties of soluble manganese at more than very low concentrations.

There is no clear evidence that the solubility of iron in the soil can be reduced by liming alone to a point where it is insufficient to supply the needs of plants. Gile and Ageton (7) have shown that the iron content of numerous plants is less on calcareous or limed soils than on non-calcareous soils, but that extreme reductions in yields on the former are observed only with those plants in which the calcium content of the plant ash is greatly increased.

Pineapples and rice which were the most seriously affected of the plants Gile studied did in fact show evidence of iron deficiency in that they developed a chlorosis which could be corrected by the external application of iron salts, but there is just as strong support in his results for a theory that the deficiency was associated with abnormal physiological phenomena as that it was due solely to an insufficient supply of iron in the absolute sense.

In an earlier work with pineapples, Gile (6) had shown that, while the iron content of pineapples was depressed on limed soils, the development of iron-deficiency chlorosis was not dependent entirely on a reduction in the iron content of the plants, since in some cases he found plants producing green leaves containing considerably less iron than was found in chlorotic plants.

Later, Gile and Carrero (8) found that rice plants developed symptoms of iron deficiency in neutral and alkaline solutions at concentrations of iron that produced normal growth in their acid solutions and they concluded finally that calcium carbonate in the soil influences the growth of rice as it diminishes the quantity of available iron through affecting the reaction.

Among other plants many trees are highly susceptible to iron-deficiency chlorosis and the history of one occurrence reported by Hendrickson (11) appears to throw some light on the mechanism of the effect of lime. On a clay soil underlaid by a calcareous substratum pear trees grew normally until the water table was lowered permitting the roots to penetrate the calcareous material. A chlorosis resulted which was remedied by spraying the leaves with an iron salt, by the injection of iron salts into the tree trunks, or by placing iron salts in contact with the tree roots. Obviously, the deeper penetration of the roots could not have decreased the amount of available iron in the soil. The only tenable deduction appears to be the one given by Bennett and Oserkowsky (3) that the additional lime disturbed the physiological processes governing the utilization of iron. Since additional iron brought about a recovery, it seems probable that the absorption of unusual quantities of lime may increase the amount of iron needed to satisfy the requirements of the plant.

Further evidence that iron deficiency is at least partly a physiological problem is found in the observation that fruit trees vary in their susceptibility to iron deficiency chlorosis according to the nature of the rootstock on which the cion is grafted (2). This indicates that the effect of liming on the availability of iron may concern not only the solubility of iron but also the factors governing permeability and translocation.

The evidence for a physiological factor in iron deficiency introduces the matter of susceptibility which appears to be governed by the plant characteristics that control the absorption of basic material.

There is no certainty that liming invariably decreases the solubility of iron in the soil. Mann (19) has shown that the concentration of iron in the water extracts of two soils was actually increased by the addition of lime to the soil and Hoffer (12) found that liming a peat soil increased the amount of iron absorbed by corn plants.

Carr and Brewer (4) have shown that ferric iron is precipitated as the hydroxide at pH 5.5, whereas the precipitation of ferrous hydroxide commences at pH 6.6 and is not complete until pH 7.9 is reached. Therefore, in order for iron to be rendered unavailable at

the reaction of soils limed at rational rates, the potential of the soil must be such as to maintain the iron in the ferric condition.

Very little is known of the oxidation-reduction equilibria of soils. Johnson (15) has reported that manganese dioxide in some Hawaiian soils holds the iron in the ferric state making it insoluble at the normal reactions of these soils and unavailable for pineapples. In support of this claim he has shown that in solution culture experiments rice developed a chlorosis when manganese dioxide or manganous sulfate were added to solutions originally containing adequate supplies of iron. The data were considered applicable to the problem of growing pineapples on the manganiferous soils, but as Kelly (17) had previously shown that this crop absorbed large amounts of manganese it is not impossible that under these conditions the manganese content of the plants may have aggravated the iron deficiency as is claimed by Rippel (23) who found that manganese sulfate added to solution cultures of barley produced a chlorosis that was corrected by the administration of iron but was not associated with a reduced iron content in the plant.

Johnson's (15) data show that the chlorosis developing in rice in his solution cultures with the manganese dioxide added was in reality due to iron deficiency inasmuch as the plants recovered their normal green color when dipped into a solution of an iron salt. The assumption that the chlorosis found when the manganese sulfate was added was a symptom of iron deficiency was not supported by similar proof and compounds of bivalent manganese will not oxidize ferrous iron. Manganese dioxide is readily formed by the oxidation of manganous carbonate, however, and the chlorosis noted by Johnson when manganous sulfate was added to his cultures may have developed as a consequence of such a reaction. It is difficult to understand though why the oxygen necessary to form manganese dioxide could not as well have oxidized the iron directly.

The appearance of chlorosis in plants is not a reliable indication of the cause, for in addition to several types of deficiency chlorosis that have been recognized, Marsh and Shive (20) have reported one caused by superoptimum concentrations of iron. The conclusion reached by Jones (16) that visible symptoms are satisfactory evidences of deficiencies only when supported by other data should be emphasized.

The intensity of oxidation in many oxidation-reduction systems has a direct relation to the hydrogen-ion concentration and some recent results (29) show that a soil may follow the general rule. Ac-

cording to this evidence, the soil becomes more reductive with increasing pH values from which it may follow that the iron of the soil might be converted to the more soluble ferrous form as a consequence of liming.

In soils that are well supplied with strong oxidants, such as manganese dioxide, the reductive effect of liming might not be sufficient to increase the solubility of iron and an increase in the concentration of soil nitrates following liming might also minimize the reductiveness.

An interesting type of iron deficiency is reported by Aston (1) who found that on some of the pumice formations of New Zealand pasturage composed of grasses and clovers failed to support sheep and cattle, although the plants grew luxuriantly with no distinct evidence of a deficiency of plant nutrients. The iron content of the pasturage was abnormally low and supplementary feeding or fertilization of the soil with iron compounds corrected the malady. A similar effect of iron deficiency on the quality of pasturage is reported from Scotland by Godden and Grimmett (9). The fact that fertilization with iron is effective in controlling this type of deficiency also differentiates it from the more common type with which fertilization with iron salts is generally of little value.

Aston gives no figures for the reactions of the soils he studied, but since they are rhyolitic pumices of fairly recent origin the pH values should be high. It is reported that some of them contain calcium carbonate, but it is doubtful that they would be as a rule more alkaline than many which have been limed according to good agricultural practise. These soils are extremely porous and the low availability of iron may be due to oxidation by the air acting in conjunction with the low concentration of hydrogen ions, but the further observation that cattle suffering from malnutrition on these pastures had abnormal amounts of copper in their internal organs may signify that the soil contains an abundance of strongly oxidative copper ions that function in a manner similar to that ascribed to manganese dioxide.

The influence of fertilization on the availability of iron is secondary to that of other factors. Iron-deficiency chlorosis of rice on a calcareous soil was intensified by applications of sodium nitrate and of ammonium phosphate (30). The effect of the former may have been due to the alkalinity of the residual sodium compounds or to the oxidative intensity of the nitrate, while the low solubility of iron phosphate formed by the reaction of the iron compounds of the soil

with the added phosphate may explain the effect of the latter, all of these effects being supplementary to that of the calcareous soil.

There is strong, if not conclusive evidence, therefore, for the judgment that if the intensity of oxidation in the soil system is sufficient to maintain the iron in the ferric condition a deficiency for susceptible plants may occur at reactions as acid as pH 6.0. Just what this intensity must be is not evident, for Robinson (24) has reported soils containing appreciable quantities of manganese dioxide at reactions above pH 6.0 on which no evidences of iron deficiency were observed.

Liming the strongly oxidative soils may constitute a real risk, but the impracticality of liming soils to a pH of 8 will greatly lessen the chance of iron deficiency on reductive soils. There is a possibility of producing an excess of soluble iron by liming strongly reductive soils such as peats and mucks.

Iron deficiency induced by liming appears to be of much less common occurrence than is manganese deficiency and far less likely to develop as a result of rational practises. However, it is much more difficult to remedy and excessive liming should be avoided on all soils as the best measure of prevention.

Where iron deficiency occurs naturally, spraying with a dilute solution of ferrous sulfate or, in the case of trees, injection into the trunk or applications in contact with the roots, of an iron salt may be effective remedies. Liberal supplies of organic matter, especially nonnitrogenous organic matter, should be helpful because of the reductive effect.

A comprehensive study of the experimental data concerning the availability of manganese and iron as affected by liming reveals many gaps in the knowledge of the subject that can only be bridged by assumptions some of which are rather weakly supported by evidence.

Manganese becomes a limiting factor on soils presumably containing small amounts of the element when these soils are limed to near neutrality. There is no support, however, for an assumption that precipitation of the soil manganese by neutralization is the only controlling factor, for the precipitated manganous hydroxide should be readily converted to the soluble bicarbonate by the carbonic acid of the soil solution. It is necessary to introduce the additional factor of oxidation into the insoluble manganese dioxide to account for the observed effects of liming. This can be done without violence to fundamental chemical principles, but there is no experimental evidence

to support the assumption. On the other hand, it is not necessary to the interpretation of the experimental data to assume any physiological disturbances consequent to liming, although these may play a part in the result.

With regard to the availability of iron the problem is more complex. It is generally considered that liming will decrease the solubility of the iron in the soil to the point of deficiency. The assumption is based largely on the results of solution culture experiments and the application of the results of these to soil conditions is by inference and without direct experimental support. On the basis of solubility data it must be conceded that iron can become deficient, except on strongly alkaline soils, only when maintained in the ferric condition and evidence has been offered to show that manganese dioxide serves as the agent of this oxidation. A critical examination of this hypothesis exposes a weakness in the argument. If the manganese dioxide is formed in the soil by the oxidation of manganous compounds, it must follow that the soil oxygen is a more intense oxidant than is the manganous dioxide, and therefore, that the soil atmosphere should accomplish the conversion of ferrous to ferric iron at least as efficiently as does the dioxide. Fluctuations in the partial pressure of oxygen in the soil might at times permit reduction of the iron compounds and the manganese dioxide may serve as a stabilizer of the oxidation potential. It is doubtful that it can intensify the oxidation process under normal conditions of soil aeration.

There is strong evidence that the deficiency of iron occasionally noted when soils are limed is partly induced by a disturbance in the physiology of plants and in the face of this it is impossible to determine to what degree the effect of lime is governed by the factor of solubility alone.

If further investigation is to be made of the effect of liming on the availability of soil manganese and iron it must be recognized that absorption by plants cannot be used as a measure of the available supply on account of the physiological interference of the calcium compounds, and the factor of oxidation-reduction potential must be put on a quantitative basis.

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FACTORS AFFECTING MANGANESE AVAILABILITY IN SOILS[1]

S. D. CONNER[2]

For many years it has been common knowledge among farmers that oats failed to do well on certain areas of low black loam soils in northeastern Indiana. This trouble has varied from partial failure to a total dying of the crop soon after the oats were up. Corn, wheat, sweet clover, and many other crops did not show any great lack of vigor on these same areas. In 1921, a quantity of soil taken from a typical area of this kind was brought to the Experiment Station for analysis and greenhouse tests.

Table 1 gives the results of the chemical analysis. It may be seen that the soil contains a high amount of nitrogen and organic matter. It is not acid and it contains a relatively large percentage of calcium and magnesium. Also, the potash and phosphate soluble in both strong and weak acid indicates that the lack of these elements could not be the reason for failure of oats.

Table 2 gives the results of the first pot test with oats on this soil. Due to the unusual action of oats compared to other crops in the field a number of treatments were given in addition to the usual nitrogen, phosphate, and potash fertilization. It will be seen that in all pots where ammonium nitrate was applied the yield was practically trebled over phosphate and potash alone. Neither sulfur, manganese,

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calcium, nor magnesium seemed to be of benefit. In the pot where the soil had been heated in live steam at 15 pounds pressure for 1 hour and where no fertilizer was added, the yield of oats was materially increased (Fig. 1).

As a result of this experiment it was thought that probably lack of early nitrification was the reason of oats failure in this field. The

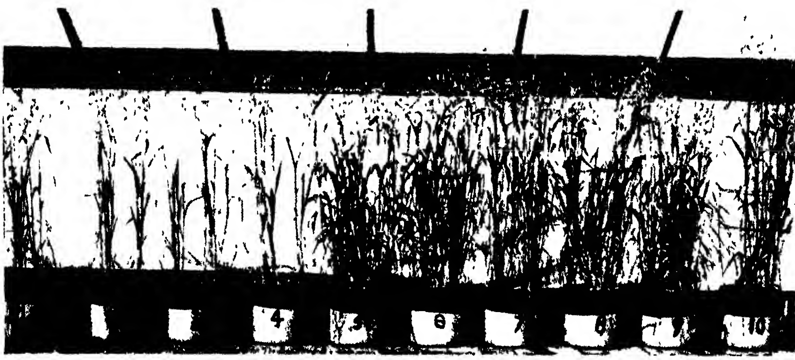

FIG. 1.—Oats on Clyde silty clay loam, 1922 (Table 2). 1, nothing; 2, P; 3, K, 4, PK; 5, PK, ammonium nitrate; 6, PK, ammonium nitrate, S; 7, PK, ammonium nitrate, SMn; 8, PK, ammonium nitrate, SMn, Ca; 9, PK, ammonium nitrate, SMn, Ca Mg; 10, steam sterilized

addition of ammonium nitrate and the sterilization of the soil would both increase the supply of available nitrogen. While the pot test with oats did not show any hint of deficiency other than that of

TABLE 1.—*Analysis of Clyde silty clay loam low in available manganese.*

Element	Soluble in HCl, sp. gr. 1.115, %	Soluble in HNO_3, N/5, %	Soluble in KNO_3, N solution, %
P_2O_5	0.25	0.052	——
K_2O	0.50	0.025	——
CaO	1.33	0.884	0.65
MgO	0.63	0.138	0.04
Mn_3O_4	0.045	0.0052	0.00
Fe and Al_2O_3	9.87	0.675	0.00
SO_3	0.09	——	——
N	0.26	——	——
pH	6.9	——	——
Hopkins acidity	100 *	——	——
Jones acidity	640 *	——	——
Volatile matter	8.37%	——	——

*Pounds of $CaCO_3$ per 2,000,000 lbs. of soil.

nitrogen, the results of the corn test which followed in the same pots gave no indication of lack of nitrogen. The corn did show a slight response to manganese and nothing else. This, however, did not

seem significant at the time. There seemed to be no reason to attribute oats failure to lack of available manganese. Although this soil had more nitrogen than higher lighter colored soil laying alongside it,

TABLE 2.—*Pot test with oats and corn, 1922.*

Pot No.	Treatment*	Grams per pot	
		Oats	Corn
1	None	37.5	37.0
2	P	32.5	35.0
3	K	32.5	35.5
4	PK	33.0	32.0
5	PKN	138.0	34.0
6	PKNS	128.0	37.0
7	PKNS, Mn	115.0	44.0
8	PKNS, Mn, Ca	126.0	47.0
9	KNS, Mn, Ca, Mg	138.0	41.0
10	Steam sterilized at 15 lbs. for 1 hour	91.0	35.0

*Treatment per pot was as follows: P = 5 grams 45% superphosphate; K = 2 grams KCl; N = 1 gram ammonium nitrate; S = 2 grams powdered sulfur; Mn = 1 gram manganese sulfate; Ca = 10 grams $CaCO_3$; and Mg = 5 grams $MgCO_3$. Two-gallon glazed earthenware pots were used.

a fertilizer was recommended for oats on this type of land composed of superphosphate and ammonium sulfate. In 1923, William Ripley of Adams County, Indiana, used 150 pounds per acre of a 4% nitrogen and 10% phosphoric acid fertilizer on such soil for oats and obtained a good crop. In one section of the field where the fertilizer drill supplied the fertilizer in alternate rows, 8 inches apart with unfertilized rows between the fertilized ones, the oats in the unfertilized rows turned yellow soon after coming up and were completely dead by harvest, while the oats fertilized with the 4–10–0 fertilizer were normal in growth at all times and filled out and ripened in good shape.

While it seemed that a practical remedy had been found for this "oats sick" soil, it did not seem reasonable that nitrogen should be needed. As a consequence, additional soil was shipped to the Experiment Station and other pot tests were undertaken. Table 3 gives the treatment and results of the second experiment. Sweet clover was first grown in the differently treated pots, the crop harvested, dried, and weighed with the results shown. Nitrate of soda gave a slight depressing action, both alone and in addition to phosphate and potash. Nitrogen in the form of animal tankage gave no benefit, but ammonium sulfate gave a slight increase. Phosphorus seemed to be the element most beneficial for sweet clover. The sweet clover stubble and roots were worked into the soil and oats were seeded. The results of this harvest were very striking in that it showed an enormous response for ammonium sulfate nitrogen but none for

either nitrate of soda or tankage. These results threw a quite different aspect on the theory that nitrogen was needed for oats on this soil. There seemed to be two possibilities, *viz.*, one that oats needed ammonia nitrogen and the other that this soil needed a physiologically acid fertilizer. A test was planned for this theory.

Table 4 gives the results of a comparison of nitrate of soda with and without a hydrochloric acid addition to the soil. Ammonium

FIG. 2.—Oats on Clyde silty clay loam, 1928 (Table 5). 1, PK; 2, PK, $MnSO_4$; 3, PK, $NaNO_3$; 4, PK, $NaNO_3$, $MnSO_4$; 5, PK, $(NH_4)_2SO_4$; 6, PK, $(NH_4)_2SO_4$, $MnSO_4$.

sulfate was used with and without carbonate of lime. This test for some unapparent reason gave no indication of any response to either additions of nitrogen or change in acidity. After a conversation with Dr. Burt L. Hartwell of the Rhode Island Experiment Station, it was decided to try manganese again as a possible factor. Table 5 gives the results of different treatments, including manganese additions to some of the same pots used in the experiment given in Table 4. These treatments and results on oats are shown in Table 5. It may be seen that nitrate of soda alone gave no response, but ammonium sulfate alone did. Manganese sulfate added to nitrate of soda gave a good response, while manganese added to ammonium sulfate did not increase the yield (Fig. 2). In this test hydrochloric acid increased the yield, but when manganese was added to hydrochloric acid the yield was lowered. The largest increase of all was with nitrate of soda and hydrochloric acid but no manganese. It would appear that manganese was of benefit only under the more alkaline conditions of pots 4 and 11. It was of no benefit on pots 2, 6, and 9 which were

more acid. In this test any increase in acidity such as would be found in pots 5, 7, and 8 had caused increased yields due probably to an increased solubility of the natural soil manganese.

TABLE 3.—*Pot tests with sweet clover and oats.*

Pot No.	Treatment*	Average weight of sweet clover 1925, grams	Average weight oats and straw, 1926, grams
1	None	19.5	21
2	Nitrate of Soda	13.5	23
3	" " " + P	62.0	24
4	" " " + K	19.0	33
5	PK	53.5	28
6	Nitrate of Soda + PK	40.5	38
7	Ammonium Sulphate + PK	68.5	145
8	Tankage + PK	51.0	33

*Treatment per pot was as follows: N = 2 grams nitrate of soda, 1.5 grams ammonium sulfate, and 3 grams tankage; P = 2 grams 45% superphosphate; and K = 2 grams KCl per pot. Three-gallon asphalted galvanized pots were used. Nitrogen was applied to each crop. PK was applied only to sweet clover.

TABLE 4.—*Pot test with oats in 1927.*

Pot No.	Treatment*	Grams dry oats and straw average
1	PK	88
2	PK + HCl	73
3	PK + $NaNO_3$	78
4	PK + $NaNO_3$ + HCl	74
5	PK + $(NH_4)_2SO_4$	87
6	PK + $(NH_4)_2SO_4$ + $CaCO_3$	77

*Treatment per pot was as follows: PK = 3 grams di-potassium phosphate; $NaNO_3$ = 2.7 grams, $(NH_4)_2SO_4$ = 2 grams; HCl = 55 cc concentrated acid; and $CaCO_3$ = 50 grams per pot. Two-gallon glazed earthenware pots were used.

TABLE 5.—*Pot tests with oats, 1928.*

Pot No.	Treatment*	Weight of oats per pot, grams
1	PK	32
2	PK + Mn	27
3	PK + $NaNO_3$	33
4	PK + $NaNO_3$ + Mn	89
5	PK + $(NH_4)_2SO_4$	95
6	PK + $(NH_4)_2SO_4$ + Mn	91
7	PK + $NaNO_3$ + HCl	109
8	PK + HCl	56
9	PK + HCl + Mn	44
10	PK + $(NH_4)_2SO_4$ + $CaCO_3$	83
11	PK + $(NH_4)_2SO_4$ + $CaCO_3$ + Mn	101

*Treatments the same as in Table 4, except no additional PK, HCl, and $CaCO_3$. New additions of $NaNO_3$ and $(NH_4)_2SO_4$ were made and 0.1 gram $MnSO_4$ was added to pots 2, 4, 6, 9, and 11.

New pot tests were then made, the treatments of which are shown in Table 6. In 1929, urea was used as a source of nitrogen. This

proved to be an error as urea evidently acted in a physiologically acid way as indicated by the 1929 oats yields where manganese gave only a small increase. This set of pots was continued in 1930 when nitrate of soda was used as a source of nitrogen and one of the untreated pots was given a manganese treatment of 0.4 gram manganese

TABLE 6.—*Pot tests with oats.*

Pot No.	Treatment*	Average weight of oats and straw, grams		
		1929	1930	1931
1a	None....	35	18	29
1b	None, 1929 ... Mn, 1930	41	45	37
2	PK, Mn...	81	57	56
3	N, K, Mn ..	128	90	60
4	NP, Mn...	203	89	89
5	NPK..	251	70	47
6	NPK, Mn.	268	100	82

*The treatment per pot was as follows: N = 2.6 grams urea in 1929 + 6 grams $NaNo_3$ in 1930 and 1931; P = 2.6 grams mono-calcium phosphate in 1929; K = 2.6 grams KCl in 1929; and Mn = 0.4 gram $MnCl_2$ in 1929 and in pot 1b in 1930. Three-gallon asphalted galvanized pots used.

chloride. In 1930, manganese gave 27 grams more oats on untreated soil and 30 grams more when used in addition to complete fertilizer (Fig. 3). This test was continued in 1931 when manganese alone gave an increase of 8 grams and 35 grams of oats when used on completely fertilized soil.

DISCUSSION

From the chemical tests and pot experiments, as well as field work on this soil, it would seem that there is apparently plenty of manganese present, but that it is in a condition of equilibrium so near the point where it is available or unavailable that different crops, different fertilizers and different climatic conditions may throw it one way or the other. It is evident that ammonium nitrate, ammonium sulfate, and urea are so acid in their action that the manganese in the soil is made available as a rule. Hydrochloric acid also seems to act in a similar manner. The growth of sweet clover and the incorporation of the stubble and roots in the soil do not seem to help in changing the manganese to a form available for oats. Steam sterilization did help to do this. Such materials as nitrate of soda and carbonate of lime lower the availability of the manganese in this soil. This adverse action of liming is in accord with work reported in Rhode Island.[8] In the pot tests conducted in 1930 and 1931, the oats growing without

[8]GILBERT, B. E., MCLEAN, F. T., and HARDIN, L. J. The relation of manganese and iron to a lime induced chlorosis. Soil Science, 22: 437. 1926.

manganese showed many white spots on the leaves which were undoubtedly similar to the "grey spot" manganese deficiency disease of

FIG. 3—Oats on Clyde silty clay loam, 1930 (Table 6). 1, 0; 2, $MnCl_2$; 5, PK, $NaNO_3$; 6, PK, $NaNO_3$, $MnCl_2$.

oats in Europe. These results are also in agreement with results reported by Samuel and Piper[4] in South Australia.

As a result of the series of pot experiments reported here it has been brought out that there are several variable factors in the growth of oats on this kind of soil. As a practical treatment there is a possibility of using such materials as sulfur or ammonium sulfate or of making a light application of manganese salts, whichever is cheapest.

[4]SAMUEL, GEOFFREY, and PIPER, C. S. Grey speck (manganese deficiency) disease of oats. Jour. Dept. Agr. S. Australia 7:696; 8:789. 1928.

In the summer of 1931 in Wells County, soybeans in areas of low black silt loam showed serious chlorotic appearance. An application of either 100 pounds per acre of ammonium sulfate or half that quantity of manganese sulfate restored the green color to the leaves.

The manganese of soils kept under reducing conditions tends to be more soluble than the manganese of soils exposed to oxidizing influences.[5] Such reduced manganese is not readily oxidized when the soil is exposed to air. This might explain why varying climatic conditions that will tend to reduce or oxidize will vary the solubility of soil manganese. The exposure of soil to live steam in the absence of oxygen for 1 hour might reduce manganese to a form available for the growth of oats.

In pot or other experiments designed to determine the need for manganese, care should be taken not only to supply all other deficient factors, but no treatment should be used that will affect the solubility of the soil manganese.

SUMMARY

A black silty clay loam soil found in northeastern Indiana often fails to grow good oats. On analysis, this soil was found to be nearly neutral in reaction. It was high in nitrogen, phosphorus, potassium, lime, and organic matter. There was a medium percentage of manganese present.

A series of pot experiments conducted during several years showed that oats were benefited by ammonium nitrate, ammonium sulfate, urea, hydrochloric acid, and by steam sterilization. Nitrate of soda, animal tankage, carbonate of lime, and the growing and turning under of sweet clover gave no benefit.

Manganese sulfate and manganese chloride increased the oats yields when used under neutral or alkaline conditions. Manganese did not show benefit when applied in addition to acid-reacting materials.

The failure of oats seems to be due to lack of available manganese and is corrected either by adding manganese or by giving a treatment that will make the soil manganese more soluble.

[5]CONNER, S. D. Soil acidity as affected by moisture conditions of the soil. Jour. Agr. Res., 15: 321–329. 1918.

THE INHERITANCE OF FUSARIUM WILT RESISTANCE IN FLAX[1]

CHARLES R. BURNHAM[2]

The disease caused by *Fusarium lini* Boll. is characterized by a sudden wilting of the flax plant at any stage from the seedling to maturity. In certain cases, plants may show yellowed or wilted leaves on one side of the stem only but extending from crown to tip, or the main stem may die and new, apparently healthy branches appear at the crown. The amount of wilt in susceptible strains has been shown by Tisdale (6)[3] and by Jones and Tisdale (2) to vary with the temperature. Between temperatures of 20° and 34° C, the amount is very high, but below 16° C and above 36° C, very little appears. The optimum for the wilt is at 24° to 28° C.

Certain variations in the results obtained by Tisdale (5) seemed explainable on the basis of genetic impurity in the parent stocks. In an experiment by the writer in which blue-flowered and white-flowered strains of flax were planted in alternate rows 10 inches apart, 1.12% of cross-pollinated, i.e., blue-flowered offspring, were observed in a total of 1,161 plants from the white-flowered individuals. All but one were tested and all these proved to be crosses. The observed number of off-types varied from none to as high as 4.29% on different plants. In the present work, in order to insure homozygosity, at least three generations of selfing preceded the crossing.

Since the environment plays such an important rôle in the expression of resistance and susceptibility, the F_2 was classified on the basis of an F_3 test. Since strains have been obtained which breed true for intermediate percentages of wilt, however, one cannot decide from an F_3 progeny test alone whether or not the observed percentage of wilting is due to segregation. At the present time it seems that nothing short of extensive F_4 tests can settle this point and provide a basis for determining the number of factors concerned in a particular cross.

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[2]The writer wishes to express his sincere thanks to Dr. R. A. Brink of the Department of Genetics and to Dr. J. G. Dickson of the Department of Plant Pathology for their suggestions and criticisms during the course of these experiments, also to Dr. M. H. Ingraham of the Department of Mathematics for aid in analyzing certain of the data. The investigations were begun by A. R. Saunders to whom credit is due for the establishment of several of the parent lines.

[3]Reference by number is to "Literature Cited," p. 748.

MATERIALS AND METHODS

Most of the original stocks used in these studies were furnished by J. C. Brinsmade of the U. S. Dept. of Agriculture. An attempt was made to include resistant and susceptible strains of widely different geographic origin. A list of this material is given below:

Wisconsin No.	C. I. No.	Origin
1	24–221–2–1	Canada
2	175–221–1–1	U. S. A.
3	176–221–1–1	U. S. A.
5	118–1–1	Argentine
6	31–220–2–2	Crete
7	25–221–2–2	North Dakota
8	40–221–2–4	India
9	36–226–3–1	Abyssinia
10	19x40 F	Russian x Indian
11	24–255	Canada
13	36	Abyssinia
14	33	Egypt
15	42	U. S. A.
16	157	Argentine
20	8–21	U. S. A.
21	112	Argentine
22	160–259	Argentine
24	– – –	English (fiber)
A	– – –	Com. Seed Flax
B	– – –	N. Dak. No. 114
105	– – –	Canada

In presenting the results the Wisconsin numbers for the strains will be used.

All the plants used for breeding in these studies were caged individually in cheesecloth cages and allowed to self-pollinate. In selecting for susceptible lines the plants were grown on wilt-free soil, and a part of the progeny was tested on wilt-infested soil. In selecting resistant lines, the plants were grown on diseased soil and the survivors were selfed. Crosses between selfed strains showing different degrees of wilt and also between those giving the same reaction but which were of different geographic origin were studied. As far as possible a single plant from each strain was selected for the different combinations. First and second generation plants for the production of F_2 and F_3 families were grown on wilt-free soil and selfed.

For the wilt-reaction, field and greenhouse tests were made. The field disease plat was started in 1924 from a shipment of wilt-infested soil from Fargo, N. Dak. Flax has been grown on this soil continu-

ously since that time. In addition, cultures of the wilt organism whose pathogenicity on flax had been determined were grown on oat hull mash and added to the soil at each planting. Preceding the 1928 test, on which the field data to be presented are based, a crop of susceptible flax was grown to get the organism well distributed. For these tests, 100-seed samples of each P_1 and F_3 family and at least 300 seeds of the F_2 were planted at the rate of 50 seeds per foot in rows 6 inches apart. The material could not be replicated owing to the large number of families to be tested, but at intervals of 14 rows there were check lots of a resistant and of a susceptible strain.

The material was planted late, July 11, in order to subject the plants to the higher temperatures which favor wilt. The first count was made about 1 week after the seedlings had emerged. Two more counts were taken at 10- to 12-day intervals, and the final count was made September 7. Only the dead plants were pulled and recorded for each count. In the last count those showing one-sided wilt or dead branches were recorded as diseased. In calculating the results these diseased plants, usually a small class, were included with the wilted plants.

RESULTS

The check lots showed considerable variability. The existence of high and low wilt areas in the plat is strikingly shown in a contour map based on these data (Fig. 1). With the exception of the first vertical row, resistant checks varied from 29 to 95% of wilt. The cause of the variability is not known. The low percentage of wilting in the first row probably was due to the fact that the plat was widened slightly in 1928, and this row was located on the new area. Germination on the plat was very poor, being only 60% for the resistant check and 56% for the susceptible check.

The wilt reactions of the parental stocks used in these studies are given in Table 1. The section headed "percentage of wilt" gives the distribution of the sib progenies into the different wilt classes. These stocks were located in the wilt plat between check rows 5 and 8 (Fig. 1). Owing to the lack of uniformity in the wilt plat, definite conclusions cannot be drawn. Since after four or five generations of selfing the lines should be homozygous, the variation in sib progenies probably is due to the lack of uniformity in the wilt test rather than to genetic segregation, although progeny tests from the extreme classes would be necessary to prove the point.

From an examination of Table 1, it is clear that certain strains are almost completely susceptible, Nos. 2, 7, 8, 9, 10, and *A* varying from 98 to

TABLE 1.—*Progeny tests of the inbred parental stocks, field wilt test, Madison, Wis., 1928.*

Strain No.	Number of generations selfed	Percentage of wilt							Number of progenies	Number of plants	Percentage of wilt
		10*	30	50	70	80–95†	95–98†	98–100†			
1	4	—	—	3	4	9	3	3	22	1,625	82.6
2	5	—	—	—	—	—	—	16	16	1,228	99.9
3	5	—	—	—	—	—	—	1	1	83	100.0
5	3	—	—	—	1	1	—	—	2	156	85.9
6	5	—	—	—	—	8	5	3	16	1,037	95.6
7	5	—	—	—	—	—	—	5	5	268	100.0
8	4	—	—	—	—	—	—	4	4	148	100.0
9	5	—	—	—	—	—	—	9	9	554	100.0
10	4	—	—	—	—	—	—	7	7	224	100.0
11	4	—	1	12	7	1	—	—	21	1,578	55.4
13	1	—	—	—	—	—	—	2	2	138	100.0
14	1	—	—	—	—	—	2	1	3	240	98.3
15	5	5	2	1	—	—	—	—	8	616	15.7
16	5	2	14	13	1	—	—	—	30	1,990	35.7
20	5	3	15	4	—	—	—	—	22	1,638	29.9
21	4	2	7	7	—	—	—	—	16	1,408	33.2
22	4	—	3	12	10	6	—	—	31	2,520	61.5
24	2	—	—	2	1	—	—	—	3	222	54.9
$5A_1$	6	—	—	—	—	2	9	29	40	2,890	98.6
$7A_1$	7	—	—	—	—	—	8	19	27	2,129	99.0
$7A_5$–1	7	—	—	—	—	—	—	13	13	1,027	99.6
$7A_5$–4	7	—	—	—	—	—	2	21	23	1,763	99.5
$8A_2$	7	—	—	—	—	2	5	17	24	1,731	97.8
$1B_1$	6	7	8	3	—	—	—	—	18	1,580	23.8
$9B_9$	7	—	—	3	—	—	—	—	3	227	50.7
$7A_5$ check	3	—	—	—	—	—	1	21	22	1,226	99.6
105 check	0	—	2	8	10	2	—	—	22	1,321	61.3

*0 to 20%.
†The class 80 to 100% is subdivided into three classes to show the distribution in detail at this end of the scale.

100% of wilt. Others are highly resistant. Nos. 15, 16, 20, 21, and 1*B*, for example, varying from 15 to 35%. Still others are intermediate, Nos. 11 and 22 showing about 50 to 60%, and Nos. 5 and 1 showing 80 to 85%. The fact that there are strains that apparently breed true for different degrees of wilting may be taken as evidence that several factors are concerned in wilt resistance. One might as-

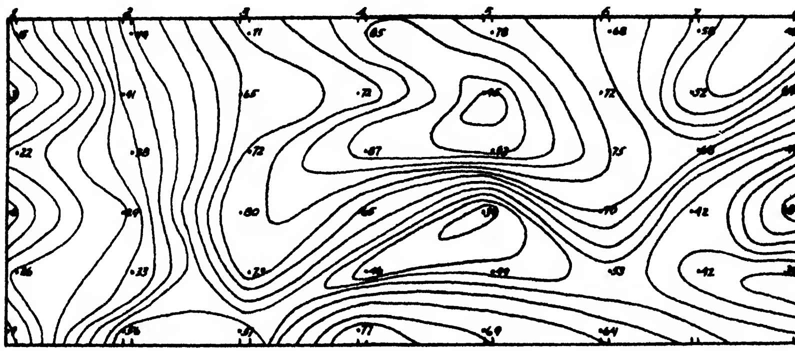

FIG. 1.—Contour map of the field wilt plat based on the percentages of wilt in replications of the resistant check, strain No. 105, 1928 test.

sume different genetic complexes for the various degrees of resistance; and, further, that each has its own normal curve of variation in development of the resistant property. Under different environments different proportions of the least resistant side of the curve would succumb. The occurrence of some wilt in resistant lines, which probably are homozygous, makes genetic analysis of the crosses more difficult. Ordinarily an F_3 progeny test reveals the genotype of the F_2 parent, but here F_4 tests are necessary to determine whether or not the observed amount of wilt in F_3 was due to genetic segregation.

F_1 AND BACKCROSS

The F_1 between susceptible and resistant strains appears to be intermediate in reaction (Table 2), although here again the results are quite variable. For further F_1 studies, a factor distinguishable in the seedling stage would be desirable to enable one to determine if all the plants were crosses. The red color in the hypocotyl of certain varieties, e.g., No. 15, might be satisfactory for this purpose.

SUSCEPTIBLE X RESISTANT, 2 X 15

Both strains are seed types. No. 2 has lilac-colored flowers and brown seeds and is of average height. No. 15 is a somewhat shorter

type than No. 2 and has blue flowers and brown seeds. Table 3 gives the distribution of the F_3 families into the dfferent wilt classes, and also that of the F_2 and of the parents in the field wilt test. Since the susceptible parent falls in the 98 to 100% class, the last class from 90 to 100% was divided into three classes. This shows in more detail the distribution at this end of the scale. In this cross there

TABLE 2.—*Wilt test of F_1's and a backcross between resistant and susceptible strains, and of the resistant parent.*

Cross	Total number plants	Number wilted	Percentage wilted
	A. Field		
S* x R* — 5A$_1$ x 16.	53	26	49.1
16 (R).	297	103	34.7
(I* x S) x R — (22 x 1) x 16.	57	40	70.2
S x R — 5A$_1$ x 15	14	14	100.0
15 (R).	638	107	16.8
	B. Greenhouse		
S x R — 5A$_1$ x 16.	73	29	39.7
16 (R).	192	37	14.1
S x R — 5A$_1$ x 16.	91	65	71.4
16 (R).	171	100	58.5

*R = Resistant; S = Susceptible; I = Intermediate.

is a piling up of the F_3 families in the higher percentages of wilt along with the F_2 and the susceptible parent. Any dividing line between resistance and susceptibility would be purely arbitrary. About 8% of the families fall in classes as resistant as the resistant parent and about 10% fall in the completely susceptible class. Tests in further generations were not carried out to determine if a series of pure types showing different degrees of intermediacy could be establised from the intermediate families. Without such a test, a factorial interpretation of the results of this cross would be mere speculation.

The same cross was selected for study during the winter months in the greenhouse where the temperature could be partially controlled. Damping-off was so severe in 1927–28 that the wilt readings were of no value. In 1928–29, virgin soil which had been steam sterilized at 15 to 20 pounds pressure for two 12-hour periods 2 days apart was used. After standing 2 weeks to air out, it was inoculated with a large quantity of the fungus which had been grown on nutrient solution, according to Wade (7). A single culture of the organism which gave the most clear cut results in a preliminary test on resistant and susceptible flax was used for this purpose. After 3 weeks to allow the organism to become established, sand was added and the benches were filled and planted, another lot of fungus being applied.

TABLE 3.—*Frequency distributions of percentages of wilt in the P_1, F_2, and F_3 generations from crosses of resistant with susceptible and of susceptible with susceptible strains, field wilt test, Madison, Wis., 1928.*

Progeny No.	Generation	Percentage of wilt												Number of families	Number of plants	Percentage of wilt
		*5	15	25	35	45	55	65	75	85	90.1–95.0	95.1–98.0	98.1–100			
15	P_1	1	4	2	—	—	—	—	—	—	—	—	—	7	—	15.7
2	P_1	—	—	—	—	—	—	—	—	—	—	—	16	16	—	99.9
2 x 15, 15 x 2	F_2	—	—	—	—	—	—	—	—	4	3	—	—	7	515	89.1
2 x 15	F_3	—	7	5	4	8	6	8	15	29	10	8	11	111	8,796	70.9
7	P_1	—	—	—	—	—	—	—	—	—	—	—	5	5	—	100
16	P_1	—	1	7	4	6	4	—	1	—	—	—	—	23	—	35.7
7 x 16	F_2	—	—	—	—	—	—	—	—	—	1	2	—	3	210	95.2
7 x 16	F_3	—	—	1	1	6	1	8	22	27	13	12	27	118	6,918	83.9
2	P_1	—	—	—	—	—	—	—	—	—	—	—	16	16	—	99.9
9	P_1	—	—	—	—	—	—	—	—	—	—	—	9	9	—	100
2 x 9	F_2	—	—	—	—	—	—	—	—	—	—	—	4	4	—	100
2 x 9	F_3	—	—	—	—	—	—	—	3	4	6	9	24	46	2,791	95.7
2	P_1	—	—	—	—	—	—	—	—	—	—	—	16	16	—	99.9
6	P_1	—	—	—	—	—	—	—	—	1	7	5	3	16	—	95.6
2 x 6	F_2	—	—	—	—	—	—	—	—	—	—	1	3	4	—	99 1
2 x 6	F_3	—	—	—	—	—	—	1	4	11	15	21	47	99	6,298	95.2

*0–10%.

A random selection of 45 of the F_3 families from the cross of No. 2 x No. 15 and the P_1 and F_2 were tested using 100-seed samples planted in rows 5 inches apart. There were five replications (six samples) of each family on four benches. Check lots of the parents were planted at intervals of about 16 rows. When the seedlings emerged, the rows were ridged slightly to permit watering in the troughs between the rows, thus avoiding free surface water around the plants, a condition which favors damping off. Soil temperatures were recorded three times daily from thermometers placed at the ends and middle of each bench. Counts were made every third day during the period of most rapid wilting. At the end of 4 to 6 weeks, when there was very little wilting, the experiment was concluded, with notes on the number of survivors.

Variations in temperature in the large greenhouse section were unavoidable. The soil temperatures at one end of benches I and II averaged 25.4° C, and on bench III, 22.8° C. At the other end they averaged 21.4° and 23.9° C, respectively. These temperatures are well within the range of temperature at which wilting freely occurs, according to Jones and Tisdale (2). The wilt results on bench IV were uniformly lower than those for the other three benches. For bench IV about one-third of sterile uninoculated soil had to be added to fill the bench. The results for this bench are considered separately.

At the time of the first count there were patches in certain rows where all the plants were dead with symptoms of damping-off. Dead plants from these areas and from progenies showing a random distribution of wilt were plated out on potato dextrose agar. For this purpose, a section of the hypocotyl at the soil line was surface sterilized by dipping in 1:1,000 mercuric chloride for 30 seconds, washed in sterile distilled water, and then plated. Out of 70 plants from the damping-off areas, only 9 showed fusarium growth. A large proportion gave a rapidly-growing organism, probably *Rhizoctonia* sp. Out of 72 plants from the other lot, 67 gave Fusarium which appeared to be the same as the form used for inoculation. The wilting in patches, therefore, was not due to *Fusarium lini*. In considering the results, rows which showed the patch-wilt are not included.

As a further check, dead plants from resistant P_1 and F_3 lines were plated out. Fusarium was obtained from 139 out of 150 such plants, demonstrating the presence of the organism in wilted plants from resistant lines. In Table 4 the results of the wilt test on the 45 F_3 families are shown. Series A is based on the averages of the four replications on greenhouse benches I, II, and III; series B on the

TABLE 4.—*Frequency distributions of percentages of wilt in the P_1, F_2, and F_3 generations of a cross of a susceptible and resistant strain (2 x 15).*

Progeny	Generation	Percentage of wilt												Number of families	Number of plants	Percentage of wilt on total
		5	15	25	35	45	55	65	75	85	90–95	95–98	98–100			
								Group A*								
2	P_1	—	—	—	—	—	—	—	—	—	—	2	10	12	1,134	99.3
15	P_1	—	2	1	4	2	—	—	—	—	—	—	—	9	1,141	36.8
2 x 15	F_2	—	—	—	—	—	—	—	—	4	1	—	—	5	471	89.4
2 x 15	F_3	—	—	—	1	5	2	3	3	13	6	8	4	45	—	80.7
								Group B*								
2	P_1	—	—	—	—	—	—	—	1	1	2	—	—	4	573	86.9
15	P_1	3	1	—	—	—	—	—	—	—	—	—	—	4	586	8.9
2 x 15	F_2	—	—	—	—	—	—	1	—	—	—	—	—	1	147	68.0
2 x 15	F_3	—	7	5	1	2	5	12	7	4	2	—	—	45	—	56.0
								Group C*								
2	P_1	—	—	—	—	—	—	—	—	—	—	—	16	—	—	99.9
15	P_1	1	4	2	—	—	—	—	—	—	—	—	—	—	—	15.7
2 x 15	F_2	—	—	—	—	—	—	—	—	4	3	—	—	—	515	89.1
2 x 15	F_2	—	3	2	3	2	3	4	3	11	6	4	4	45	—	71.1

*A, based on five replications, on averages of benches I, II, and III, greenhouse, 1928–29; B, based on the results in bench IV (no replications), greenhouse, 1928–29; and C, field test of the same F_3 families, 1928.

results from bench IV; and series C on the 1928 field results for the same families. Fig. 2 shows the results in graphical form. The graphs show the percentages of the F_3 families which fall in each class, and therefore may be compared directly.

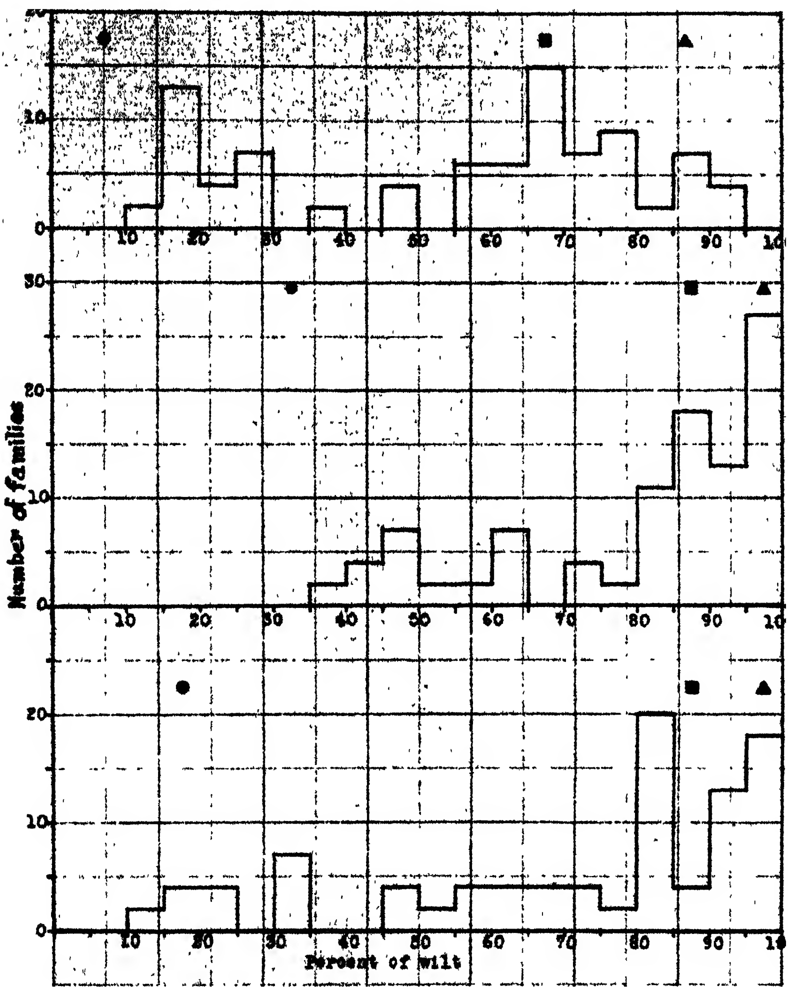

FIG. 2.—Frequency distributions of 45 F_3 families from the cross of a susceptible with a resistant strain (2x15). Upper, test in greenhouse, bench IV. 1928–29; middle, test in greenhouse, average of four replications, on benches I, II, III, 1928–29; bottom, test is filed, 1928. ▲Susceptible P_1 ■F_2 generation mean. •Resistant P_1.

On the whole, there was more wilt in the greenhouse than in the field; but, with the exception of bench IV, the general type of distribution is the same. Pearson's coefficient of correlation was calculated for the field and greenhouse results (3). No correction was made for the fact that both curves are skew. The correlation between field results and the averages for benches I, II, and III is $0.83 \pm .03$, and with those on bench IV, $0.84 \pm .03$. Although the curve based on the bench IV results is quite different, the correlation is as high as it is for the other results. The correlations are high, and indicate that, in general, families that show high or low percentages in the field give the same reaction in the greenhouse.

No attempt was made to use a single physiologic form of the fungus in the greenhouse. The culture used was isolated from a single plant. Since there probably were more strains present in the field, certain families that were susceptible in the field should have been resistant in the greenhouse. In no case was this result obtained. Possibly the cross was not segregating for resistance to the additional strains in the field.

In the greenhouse tests the light conditions were very poor. This, combined with the high temperature, produced very weak-stemmed and elongated plants. In the first few counts certain families, including the resistant parent, showed very little wilt. In marked contrast, others, including the susceptible parent, showed large numbers of wilted plants. As the experiment continued, more and more wilt appeared in the resistant progenies until certain ones had wilted considerably. If the percentage of wilt that appeared in the first two counts is calculated, there is sharp differentiation between resistant and susceptible F_3 families on benches I, II, and III. Thirteen of the 45 families, or about one-fourth, fall in the lower or resistant class. Again the bench IV results do not conform, giving no such separation.

At the final count, the survivors were grouped roughly into three classes, as follows: (a) Those very badly affected, all but the tip leaves having died; (b) those affected, but showing dead leaves only on the lower half of the plant; and (c) those entirely healthy with all the leaves green and normal. The symptoms in classes a and b probably are not due to wilt alone but to wilt combined with poor light and high temperature. The plants were plated out on acidified potato dextrose agar as described previously. The results (Table 5) for segregating and for resistant F_3 families are very similar. In group a, the Fusarium was isolated from 58 out of 61 plants, or

95.1%; in group b, from 249 out of 348, or 71.6%; and in group c, from 199 out of 444, or 42.3%. The degree of success was highest in the lot most affected, but the significant fact is that a high percentage of the plants appearing entirely normal contain the fungus at a region considerably above the point where most of the infection probably occurred. In this particular resistant strain of flax, No. 15, apparently resistance does not depend on the ability of the plant to prevent the fungus from entering its tissues.

TABLE 5.—*Results of plating the surviving plants in F_3 resistant and F_3 susceptible families on potato-dextrose agar, greenhouse test, Madison, Wis., 1928–29.*

Type of plant		b*			c*		
F_3 class	Number of families	Percentage with Fusarium	Percentage sterile	Total plants	Percentage with Fusarium	Percentage sterile	Total plants
Segregating	23	76.6	19.7	137	53.2	39.2	158
Resistant	10	69.7	28.0	211	49.3	44.1	286
Deviation of resistant.	..	−6.9	+8.3	—	−3.9	+4.9	—

*b = Plants showing some yellowing, and with dead leaves at the lower nodes; c = Plants appearing entirely healthy, all the leaves being green and normal.

A second series was attempted in the greenhouse in the same soil. Duplicate lots show so much variation that the results cannot be analysed. A bad nematode infestation may have been responsible for the variation, although no evidence is available that this was the cause. Damping-off also was much worse in this series.

SUSCEPTIBLE X RESISTANT, 7 X 16

Strain No. 7, known as Williston Golden, has white flowers, orange anthers, and cloudy-yellow seeds. No. 16 is an Argentine selection with blue flowers, blue anthers, and brown seed. The field results on this cross are given in Table 4. The F_2 shows a very high percenatge of wilt, only about 5% of the plants surviving.

Here again, as in the cross No. 2 x No. 15, only a few of the F_3 families are as resistant as the resistant parent. Other families fall in intermediate classes.

The number of genetic factors concerned in the cross is problematical. This cross also involved differences in flower and seedcoat color. In the blue-flowered class there were 60 brown and no yellow-seeded; in the white-flowered class, 14 brown and 8 yellow-seeded plants. This suggests a 3:1 ratio for flower color and a 15:1 for seedcoat color. Since none of the blue-flowered plants had yellow

seeds, apparently one of the two factors for seedcoat color is closely linked to the one for flower color, or is due to the same factor as described by Tammes (4) and Kappert (1). The average amount of wilt from brown and from cloudy-yellow seeded F_2 plants were $83.1 \pm 2.2\%$ and $93.7 \pm 1.9\%$ respectively. This difference is 4.8 times its probable error and possibly is significant. The number of yellow-seeded plants is too small, but this is the type of result expected if one of the factors for seedcoat color is linked with susceptibility, since the susceptible parent was yellow-seeded.

The average amount of wilt in the F_3 families from blue-flowered F_2 plants was $82.0 \pm 1.5\%$, and from white-flowered ones $87.6 \pm 1.86\%$. The difference of $5.6 \pm 2.4\%$ probably is not significant. Therefore, if there is linkage between seedcoat color and susceptibility, the factor which is independent of flower color must be concerned. In this cross and in the No. 2 x No. 15 cross the percentage of wilt in the F_2 is considerably higher than the average for the F_3 families. The results for No. 2 x No. 15 are, for the F_2, $89.0 \pm 0.8\%$, for the F_3, $71.0 \pm 1.6\%$, *n* being 7 and 111 families, respectively. The difference is statistically significant, $\frac{\text{dev.}}{\text{P.E.}} = 10.1$, although the number of F_2 families is small.

Additional crosses were studied but only in the field. From a cross of No. 2 x No. 6, (susceptible x near-susceptible) 5 out of 99 F_3 families belong to classes more resistant than the No. 6 near-susceptible parent (Table 3). In view of the wide differences in reaction of sib families of No. 6, this result is quite possibly due to variations in the wilt test and not to transgressive segregation of minor factors for resistance carried by the two parents.

In a cross of two susceptible strains of different origin, No. 2 x No. 9, American x Abyssinian, almost a third of the 46 F_3 families show some resistance (Table 3). This strongly indicates transgressive segregation, but one cannot be certain without tests in further generations.

A large number of crosses was carried only to the F_2 and studied in the field (Table 6). The differences between different crosses are not very great, nor do they seem consistent. Crosses of near-resistant, R(—), either by near-susceptible, S(—), or by resistant gave nearly the same amount of wilt. Crosses between susceptible strains gave practically complete wilting. One significant result is the high percentage of wilt shown in crosses between different resistant strains (Table 6, last group of crosses). Possibly these resistant strains,

Nos. 15, 20, and *B*, carry different factors for resistance, although other explanations are possible. Certain selections from these F_2's should combine the factors for resistance from each parent. The point has not been tested, but such a strain might be much more resistant than the parent forms. With the small amount of natural crossing that occurs in flax, a mixture of such strains, genetically different, might soon give rise to a considerable percentage of susceptible plants in a lot which had been resistant.

TABLE 6.—*F_2 results from crosses of different strains of flax, field wilt test, 1928.*

Type	Cross	Total plants	Per-centage wilted	Type	Cross	Total plants	Per-centage wilted
R x S.	2x15	268	88.8	S x I	2x11	146	88.4
	15x2	247	89.5		$5A_1$x11	255	89.4
	Ax15	902	88.7		11x$5A_1$	304	94.4
					Ax11	344	94.5
					22x8	214	99.5
R x S (—)	15x1	207	77.3		Ax22	572	97.4
	6x15	500	91.0		22xA	584	94.9
R (—) x S	7x16	210	95.2	S (—) x I	22x6	417	86.6
	Ax16	506	89.6		6x22	492	73.0
	20x2	282	92.2				
	Ax20	412	97.6				
	21x9	244	96.7	SxS	2x9	212	100
	21xA	395	95.9		Ax2	459	99.8
	Ax21	323	92.9		Ax9	310	97.7
	Ax1B_1	112	98.2		Ax10	149	100
	Ax9B_9	278	93.9		AxA	896	99.5
R (—) x S (—)	6x16	354	65.2	S (—) x S	1x2	372	98.1
	6x11	566	80.0		2x6	235	99.1
	21x1	179	78.8		Ax1	296	98.6
	1B_1x5	145	76.5		6xA		
	6x1B_1	66	95.4		Ax6	1234	98.0
R x I	22x15	49	63.3	RxR (—)	15x20	208	78.8
					15x1B_1	327	80.1
					20x9B_9	230	80.9
R (—) x I	22x20	335	86.0				
	22x1B_1	239	87.9				

SUMMARY

1. According to the field wilt test of selections from a collection of flax varieties, certain strains are completely susceptible, others highly resistant, and others breed true for intermediate degrees of susceptibility.

2. The evidence indicates that the wilting in pure resistant strains is not due to segregation.

3. In one resistant strain, No. 15, the only one tested by plating, it was possible to isolate the organism from stem tissue of plants

which apparently were completely healthy. Here, resistance cannot be due wholly to a corking off of the Fusarium before it reaches the vascular tissue, as was reported by Tisdale (5).

4. In the F_3 from the cross of a resistant with a susceptible strain, only a small percentage of the families were as resistant as the resistant parent. Most of the families fell into the highly susceptible classes. A few showed intermediate degrees of resistance, but whether these were pure or segregating was not determined. A factorial interpretation of the results would be purely arbitrary.

5. A slight indication of linkage between susceptibility and one of two duplicate factors for yellow seedcoat color was obtained.

6. Crosses between certain resistant strains of different origin showed a high percentage of wilt, indicating that they may carry different factors for resistance. This may be important in the breeding of new resistant strains.

7. A small amount of natural crossing was observed, 1.12%, although the amount varied from none to 4.29% on different plants.

8. The great need in the study of wilt resistance seems to be the development of a technic whereby comparable results can be obtained at different times. This involves a more thorough understanding of the factors which affect the expression of resistance and susceptibility.

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NITRATE-ASSIMILATING SOIL BACTERIA[1]

F. B. SMITH and P. E. BROWN[2]

It is known that the addition of straw, corn stalks, and other materials of a wide carbon-nitrogen ratio to soils usually brings about a reduction in the nitrate content of the soil and that this reduction is largely due to the assimilation of the nitrates by soil microorganisms. It has also been shown in certain experiments that nitrate assimilation in soils growing timothy is much greater than in soils growing corn and that the nitrate content of bluegrass sod is low. Thus, the process of nitrate assimilation is recognized to be of much practical significance and in some cases crop yie'ds have actually been seriously affected when the microbial assimilation of nitrates is stimulated to an undesirable extent.

Some investigations have been conducted to determine the conditions wh'ch favor nitrate assimilation in soils, but no comprehensive study of the nitrate-assimilating organisms has been recorded. The purpose of this investigation was to identify some of the bacteria commonly occurring in soils which have a high nitrate-assimilating power.

HISTORICAL

Gerlach and Vogel (2)[3] isolated seven species of "protein-building bacteria" from soil and manure. They were described as short, actively motile, non-spore-forming rods. Gelatin was liquefied rapidly. Gas was not produced in grape sugar and nitrate solution cultures. They did not grow on nitrogen-free medium. Nitrate and ammonium salts were utilized as sources of nitrogen. A green, fluorescent pigment was formed on agar and gelatin. When a nitrate solution was inoculated with species of these bacteria, nitrite was formed but soon d'sappeared. Ammonia formation was not detected. The total nitrogen of the solutions inoculated with these organisms was the same at the end of the experiment as in the beginning. It was concluded that the nitrate nitrogen had been assimilated. The organisms were not sufficiently described to permit of identification.

Löhnis (3) made glycerol-nitrate solution enrichment cultures from a soil and isolated bacteria which he identified as *Bact. radiobacter*, *Bact. lactis viscosum*, *Bact. turcosum*, and *Bact. fluorescens*. Later,

[1]Contribution from the Department of Soils and Crops, Iowa State College, Ames, Iowa. Received for publication January 22, 1932.

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[3]Reference by number is to "Literature Cited," p. 754

from a soil treated with mannitol, he (4) isolated an organism which readily assimilated large amounts of nitrate. He described the organism as a short, non-spore-forming, Gram-negative rod, actively motile by means of peritrichic flagella. He gave the name *Bacterium agreste* to this organism.

Murray (5) studied the effect of straw on the types of bacteria present in soil. He found the following organisms occurring in the treated soils: *B. subtilis*, *B. ginglimus*, *B. punctiformis*, *B. siccus*, *B. liodermos*, *B. verticillatum*, *B. megatherium*, *B. sublanatus*, *Bact. oxylacticum*, *M. lactis*, *M. coronatus*, *B. mesentericus*, *B. detrudens*, *Bact. lactis*, *M. simplex* and *M. radiatus*. The predominating type in all cases was the Gram-positive, proteolytic, spore-bearing strepto-bacillus. The straw did not seem to stimulate any group of bacteria. The *B. subtilis* type predominated in all soils treated with straw and also in the check soil and in the field soil. Although straw stimulated bacterial reproduction, it was a reproduction of types already present in the soil,, and no special group was favored. Of all bacteria present in the field soil, 40.6% were *B. subtilis* and 49.5% were *B. megatherium*, whereas in the soil treated with straw, 93.0% were *B. subtilis*. It was concluded that straw had no effect on the kind of bacteria present in the soil. The same types predominated in straw-treated soil as in soil without straw. Murray, however, made his isolations 53 weeks after treatment of the soil with straw. If he had made his isolations during the time the soil was low in nitrate-nitrogen it is very probable he would have found different types of bacteria present.

Smith and Brown (6) isolated a large number of nitrate-assimilating bacteria. Many of these bacteria occurred as short, Gram-negative, non-spore-forming rods which produced a yellow or green pigment in nitrate agar.

METHODS OF PROCEDURE

Rapid nitrate assimilation was induced in Carrington loam which had an initial nitrate content of about 50 p.p.m. by treating with 1% dextrose or 2% dry oat straw. When straw was used, it was ground to pass the 0.5-mm sieve and was well mixed with the soil. The moisture content was adjusted to 50% of the saturation capacity and the soil incubated in the greenhouse for 1 week, after which qualitative tests showed the nitrate content of the soil to be very low.

A large composite sample of the soil was taken from which enrichment cultures (Fig. 1) were made, using 10 grams of the moist soil in 100 cc of a culture medium containing 1% glucose, 0.1% potassium

nitrate, 0.05% di-potassium phosphate, and 0.02% calcium chloride. The enrichment cultures were incubated at 25° C for 3 days then dilution plates were poured on nitrate agar of the same mineral composition as the nitrate solution used for enrichment cultures. Typical colonies were selected and plates poured again to secure the or-

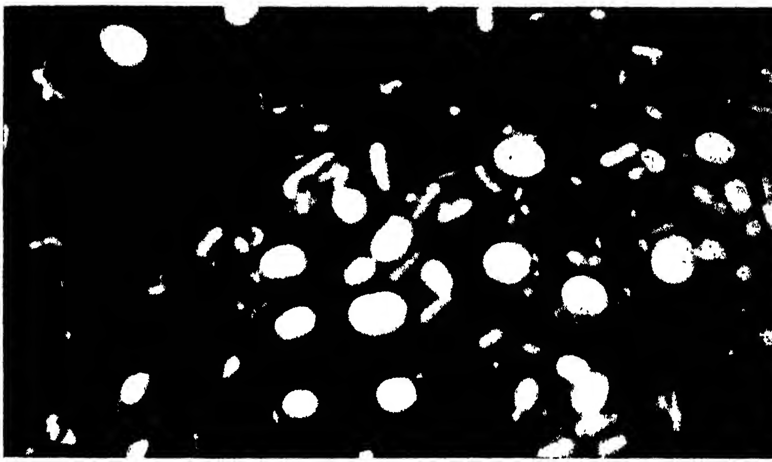

FIG. 1.—From surface-film of enrichment culture 3 days old, nigrosine mount. × 1900.

ganisms in pure culture. The Manual of Methods for Pure Culture Study of Bacteria, published by the Society of American Bacteriologists, was followed in the study of the characteristics of the bacteria.

ORGANISMS STUDIED

Azotobacter chroococcum

Characteristic Azotobacter growth occurred on the surface of enrichment cultures. Relief mounts made by spreading a loopful of the surface film from the enrichment culture on a clean glass slide, drying, and covering thinly with a saturated aqueous nigrosine solution. Preparations made in this manner showed an abundance of large, coccus-like rods (Fig. 1). The organism was obtained in pure culture by repeated plantings on mannitol-nitrate agar.

Nitrate assimilation tests with *Azotobacter chroococcum* showed it to be an active nitrate assimilator in the soil when 1% of straw was added or in mannitol-nitrate solution, but less nitrate was assimilated in soil cultures when dextrose was used.

Aerobacillus asterosporus

This organism was isolated from Carrington loam which had been treated with 1% of dextrose.

Nitrite was produced from nitrate in solution cultures. A small amount of ammonia was produced in nitrate solution cultures inoculated with this organism. No nitrogen was lost from these cultures, the total nitrogen was the same 7 days after inoculation as it was before inoculation, but the nitrate had disappeared.

Radiobacter No. 1

This organism was found most frequently of all the bacteria isolated. It occurred as small rods, 0.5 x 2 microns, Gram-negative, and actively motile by means of peritrichous flagella. Growth on dextrose-nitrate agar slants was abundant, filiform, glisttening, smooth, moist, soft, and transparent. A ring was formed in nutrient broth after 6 days, and abundant membraneous sediment. Gelatin was not liquefied in stabs after 15 days. Colonies on dextrose-nitrate agar were 5 to 8 mm in diameter, with transparent margin and opaque center, forming concentric rings in old colonies. Growth on potato was scanty, yellow, and the potato became green. A thick, slimy growth was produced in milk, the milk becoming brown after 21 days. Litmus milk was reduced in 4 days. Starch was not hydrolized. An alkaline reaction was produced in dextrose, sucrose, maltose, lactose, glycerool, and mannitol-nitrate agar. Nitrite was produced from nitrate, but the nitrite soon disappeared. Ammonia formation was not detected. Thirteen milligrams of nitrate-nitrogen in 100 cc of a nutrient solution disappeared in 7 days and the total nitrogen remained the same when the solution was inoculated with a culture of this organism. Indol was not produced. The optimum temperature was 28° C. The organism is aerobic, facultative.

Pseudomonas fluorescens

This organism was usually present in soils treated with oat straw, but it was found to utilize less nitrate nitrogen than the cultures of Radiobacter. Some nitrite was produced, but it soon disappeared. Five other species of Pseudomonas were found that apparently reduced the nitrate to nitrite.

Achromobacter spp.

Four species of this genus were isolated from soil which had been treated with straw. They occurred usually as short rods, non-motile, Gram-negative. Endospores were not formed. Gelatin liquefaction

was usually stratiform. Growth on agar slants was flat, spreading, and irridescent. Litmus milk was peptonized. Growth on potato was brown, starch was not hydrolized, and indol was not produced. Nitrate was reduced to nitrite, but the nitrite soon disappeared. Ammonia production was not detected.

DISCUSSION

A number of investigators have reported increased nitrogen fixation following the application of dextrose or straw to soils. One would expect, therefore, to find species of nitrogen-fixing bacteria present in such soils. However, *Azotobacter* might not be present in all cases, especially in soils more acid than pH 6.0.

Radiobacter is the name employed here to designate *B. radiobacter* which some refer to as the Radiobacter group. Reference to the Radiobacter group implies the existence of different species, or at least different strains. Variations in the characteristics of these organisms have been recognized, but sufficent information is not available for differentiation of species. A number of cultures of Radiobacter have been isolated from various soils for a more detailed study of their characteristics.

Aerobacillus asterosporus, a facultative-aerobic organism, was the only spore-former isolated. This organism grew on a nitrogen-free medium but was capable of assimilating nitrates rapidly in mannitol or dextrose-nitrate solution cultures.

Several species of Pseudomonas and Achromobacter were found and in pure culture studies some of them assimilated nitrates readily, whereas others apparently reduced the nitrate to nitrite in which form it accumulated.

Species of Azotobacter are well known for their nitrogen-fixing ability. The cultures of Radiobacter were found closely associated with Azotobacter and it is claimed (1) that *Aerobacillus asterosporus* may fix small amounts of nitrogen. It would seem, therefore, that the aerobic, nitrogen-fixing bacteria or closely associated species may be largely responsible for the assimilation of nitrates when straw and other carbonaceous materials poor in nitrogen are applied to the soil.

SUMMARY

Species of Azotobacter, Radiobacter, Aerobacillus, Pseudomonas, and Achromobacter were isolated from soils in which nitrate assimilation occurred and tests with these bacteria in pure culture showed that they were able to assimilate nitrates.

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A CUMULATIVE TRANSGRESSIVE SEGREGATION IN WHEAT[1]

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While transgressive segregation in wheat has been noted on several occasions (1, 4, 5, 6, 7),[3] the case here reported is regarded as being of evolutionary interest.

Utac wheat is a pure-breeding segregate from a cross between the varieties Sevier and Dicklow. These two parent varieties are of intermediate spike density, the length of 10 internodes in Sevier being 33.7 ± 0.81 mm and in Dicklow 50.5 ± 0.64 mm. Approximately one-fourth of the progenies were distinctly more dense than either parent, while another one-fourth was distinctly more lax than either parent. After some years of nursery yield tests one of the dense progenies gave considerable economic promise and was advanced to the plat tests in the Utah Agricultural Experiment Station. Continuing to yield well, it was given the name "Utac", as an abbreviation of "Utah A. C". Its spike density for 10 spikelet internodes was $25.2 \pm .296$ mm. In order to unite the winterhardiness and the smut resistance of Ridit wheat with the high yield and standing ability of Utac, a cross was made between these varieties. The spike density for 10 spikelet internodes of Ridit was found to be $44.5 \pm .234$ mm. Out of these came another transgressive segregation which is cumulative over the one obtained in Utac as compared with its two parents. One-fourth of the offspring was more dense than even the dense Utac and the lax fourth more lax than lax Ridit. Statistical study shows the transgressive differences to be distinct, as they are 10 and 26 times the respective probable errors.

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director August 8, 1931. Received for publication January 11, 1932.

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[3]Reference by number is to "Literature Cited," p. 764.

The parents also differed in awn length and in grain color, which differences are summarized in Table 1.

TABLE 1.—*Contrasted characters in the parents, Ridit and Utac.*

Parental variety	Awns	Spike density	Grain color
Ridit	Short apical awns 2	Lax	Red
Utac.	Fully awned awns 4	Dense	White

EXPERIMENTAL PROCEDURE

The cross between Ridit and Utac was made in 1927. Several F_1 plants were harvested from one of which about 400 kernels were seeded in the fall of 1928 in rows 1 foot apart and spaced 3 or 4 inches in the row. The data taken on the F_2 plants consisted of spike density, grain color, awn classes, and culm length.

In the fall of 1929 an F_3 progeny row was seeded with grain from each of the 398 F_2 plants. As each F_2 plant seeded one F_3 progeny row, the breeding behavior of the F_3 progenies was the basis for classifying the F_2 plants. The rows were again 1 foot apart and the kernels spaced 2 or 3 inches apart in the row with 40 to 60 kernels to the row. After each tenth progeny the two parental varieties, Ridit and Utac, were sown side by side, spaced and seeded at the same time and in the same manner as were the progeny rows. In all, there were 78 parental rows and 398 progeny rows.

Spike density was obtained by measuring 10 spikelet internodes on a leading spike of each plant, the measurement being taken along the middle part of the rachis, usually beginning about the third spikelet internode from the base of the spike, so as to avoid the variation in internode length which occurs both at the base and at the apex. Awn behavior was determined for each plant by observation. To obtain grain color, one head from each plant was threshed. The segregation was so clearcut as to be determined immediately by inspection. No theory of inheritance was advanced until all data were taken, recorded, and calculated.

SPIKE DENSITY

On the first 40 plants from each row taken at random, 10 rachis internodes were carefully measured on a leading spike of each plant. Later, after all necessary data in the laboratory had been tabulated, the mean spike density and the coefficient of variability (C.V.) of each parent row and each progeny row were calculated. (See Fig. 1.)

Table 2 indicates whether or not the F_3 progenies segregated. Each progeny was placed in the table according to its mean spike density and according to its coefficient of variability. Data in this

TABLE 2.—*The F_3 progenies grouped according to mean spike density classes and coefficient of variability (C. V.) classes.*

Length of 10 internodes, mm															C.V. classes
18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	%
—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	2.00
1	—	—	—	—	—	—	—	—	—	3	6	13	5	2	4.00
5	8	4	1	—	—	—	—	—	1	9	23	19	6	2	6.00
2	28	15	3	—	—	—	—	—	—	2	5	2	—	—	8.00
—	14	8	1	—	—	—	—	—	—	1	1	—	—	—	10.00
—	3	1	—	—	—	—	—	—	—	—	—	1	—	—	12.00
—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	14.00
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16.00
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18.00
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20.00
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	22.00
—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	24.00
—	—			1	3	1	2	—	—	—	—	—	—	—	26.00
—	—	—	1	2	2	3	2	1	—	—	—	—	—	—	28.00
	—			3	4	7	1	1	—	—	—	—	—	—	30.00
—	—	—	2	13	10	11	4	2	2	—	—	—	—	—	32.00
—	—	—	4	7	14	11	3	1	—	—	—	—	—	—	34.00
	—	1	1	12	21	4		—	—	—	—	—	—	—	36.00
—	—	—	2	5	17	7	1	1	—	—	—	—	—	—	38.00
				1	2	3		—	—	—	—	—	—	—	40.00
	—	—			—	—	—	—		—	—	—	—	—	42.00
—	—	—	—	1		—	—	—	—	—	—	—	—	—	44.00

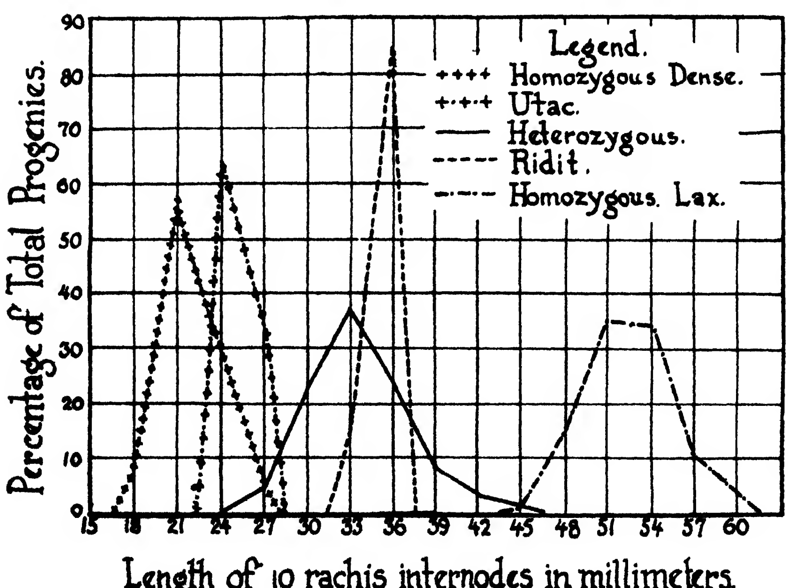

FIG. 1.—Spike density curves of Ridit and Utac parents and of the three progeny groups, homozygous dense, heterozygous, and homozygous lax.

table prove that there are three distinct groups, *viz.*, one with dense spikes and another with lax spikes, both with low coefficients of variability, and a third group with a high coefficient of variability. The first two are regarded as true-breeding forms and the third as segregating, as all of the progenies in this group have coefficients of variability sufficiently high to show clearly that they are heterozygous.

In Table 3 the progenies are compared with the parental types. The spike-density classes of the means of Ridit and Utac parental rows and the mean of F_8 progenies are arranged according to coefficient of variability classes and according to length of 10 rachis internodes into five groups, as follows: Ridit, Utac, homozygous dense, heterozygous, and homozygous lax.

The coefficients of variability of the Ridit parent rows have a mean of 4.83%, with a range from 3.7 to 6.6%. The coefficients of variability of the Utac rows have a mean of 10.6%, with a range from 7.7 to 14.25%.

An F_8 progeny was regarded as homozygous when its coefficients of variability had about the same range as those of the parental rows. For the homozygous dense progenies the mean was 8.39%, with a range of from 4.3 to 14%. In the homozygous lax group the mean was 5.75%, with a range of from 2.9 to 11.9%. The coefficient of variability mean for the heterozygous group was 33.65%, with a range of from 23 to 45.1%. There is a marked gap between the most variable progeny classed as homozygous dense (C.V. = 14%) and the least variable progeny classed as heterozygous (C.V. = 24%). With this measure, homozygosity and heterozygosity are clear-cut. Only a few of the homozygous progenies showed less variability than 4% or greater variability than 10%, as contrasted with the heterozygous group in which most of the progenies range between 28 and 38%.

The data of the range of densities of the parents and of the F_8 progenies are presented in a summarized fashion in Table 4. This table gives also the mean of mean spike densities of the Ridit and the Utac parent rows and of the three groups of F_8 progenies, together with the range of the coefficients of variability (C.V.) and the mean of mean coefficients of variability for the five groups. The mean of all the Ridit parental rows was 44.5 mm with a mean coefficient of variability of 4.83%. The mean spike density of all the lax progenies was 52.1 mm and the mean coefficient of variability 5.75%.

The mean of the mean spike densities of the Utac parent was 25.2 mm with a mean coefficient of variability of 10.60%, as compared with the group of lax progenies which had a mean spike density of 22 mm and a mean coefficient of variability of 8.39%.

TABLE 3.—*Mean spike density and coefficient of variability (C. V.) classes of Ridit and Utac wheats and of three groups of F_3 hybrid progenies.*

Parent or progeny	Spike density classes															C. V. classes
	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	Total	%
Ridit	—	—	—	—	—	—	—	—	4	19	—	—	—	—	—	23	4.00
	—	—	—	—	—	—	—	—	2	14	—	—	—	—	—	16	6.00
Total and mean	—	—	—	—	—	—	—	—	6	33	—	—	—	—	—	39	4.83
Utac	—	—	2	2	—	—	—	—	—	—	—	—	—	—	—	4	8.00
	—	—	11	6	—	—	—	—	—	—	—	—	—	—	—	17	10.00
	—	—	9	6	—	—	—	—	—	—	—	—	—	—	—	15	12.00
	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	3	14.00
Total and mean	—	—	25	14	—	—	—	—	—	—	—	—	—	—	—	39	10.60
Homozygous dense	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	4.00
	5	8	4	1	—	—	—	—	—	—	—	—	—	—	—	18	6.00
	2	28	15	3	—	—	—	—	—	—	—	—	—	—	—	48	8.00
	—	14	8	1	—	—	—	—	—	—	—	—	—	—	—	23	10.00
	—	3	1	—	—	—	—	—	—	—	—	—	—	—	—	4	12.00
	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2	14.00
Total and mean	8	55	28	5	—	—	—	—	—	—	—	—	—	—	—	96	8.39
Heterozygous	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	2	24.00
	—	—	—	—	1	3	1	2	—	—	—	—	—	—	—	7	26.00
	—	—	—	1	2	2	3	2	1	—	—	—	—	—	—	11	28.00
	—	—	—	—	3	4	7	1	1	—	—	—	—	—	—	16	30.00
	—	—	—	2	13	10	11	4	2	2	—	—	—	—	—	44	32.00
	—	—	—	4	7	14	11	3	1	—	—	—	—	—	—	40	34.00
	—	—	1	1	12	21	4	—	—	—	—	—	—	—	—	39	36.00
	—	—	—	2	5	17	7	1	1	—	—	—	—	—	—	33	38.00
	—	—	—	—	1	2	3	—	—	—	—	—	—	—	—	6	40.00
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	42.00
	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	44.00
Total and mean	—	—	1	10	45	74	47	14	6	2	—	—	—	—	—	199	33.65
Homozygous lax	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	2	2.00
	—	—	—	—	—	—	—	—	—	—	3	6	13	5	2	29	4.00
	—	—	—	—	—	—	—	—	—	1	9	23	19	6	2	59	6.00
	—	—	—	—	—	—	—	—	—	—	2	5	2	—	—	9	8.00
	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	2	10.00
	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	12.00
Total and mean	—	—	—	—	—	—	—	—	—	1	16	36	53	11	4	103	5.75

Table 4 proves that there are three definite groups of F_3 progeny when classified according to spike density and that transgressive segregation is in both directions, toward greater denseness and laxness, but particularly in the direction of greater laxness.

TABLE 4.—*The range of mean spike densities and the mean of mean spike densities of Ridit and Utac rows and of three groups of F_3 families, together with the range of the coefficients of variability (C. V.) and the mean of the mean coefficients of variability for the parents and for the F_3 families.*

Strain	Spike density range	Mean spike density, mm	C. V. range	C. V. of mean spike densities
Ridit parent.	42.6 – 46.1	44.5	3.7 – 6.6	4.83
Utac parent	23.1 – 26.7	25.2	7.7 14.25	10.60
Homozygous dense	18.1 – 27.6	22.0	4.3 - 14.0	8.39
Heterozygous.	23.6 – 43.7	33.4	23.0 – 45.1	33.65
Homozygous lax	46.2 – 60.8	52.1	2.9 11.9	5.75

Table 5 is given in order to show that transgressive segregation in spike density actually occurred between the dense parent and dense progenies, on one hand, and between the lax parent and lax progenies, on the other. The table gives the difference in mean spike density between the Ridit parent and the homozygous lax progeny and the probable error of the difference as well as the difference in mean spike density between the Utac parent and the dense progeny and the probable error of the difference.

TABLE 5.—*The difference in mean spike density in the parents and lax and dense progenies and the probable error of the difference.*

Strain	Number of rows	Difference of mean spike density	Difference / P. E.
All lax progenies....	103	52.1 ± .210 mm	26
Ridit.......... ...	39	44.5 ± .234 mm	—
Difference....... ..	—	7.6 ± .314 mm	—
Utac...	39	25.2 ± .296 mm	10
Dense F_3.........	96	22.0 ± .130 mm	—
Difference.........	—	3.2 ± .323 mm	—

In the case of Ridit and the lax progeny the difference is about 26 times the probable error, while the difference between the dense progenies and the Utac parent is 10 times the probable error. The probable error in relation to the difference gives a very high probability that transgressive segregation in spike density actually occurred.

A count of the number of families in each group shows that there are 96 homozygous dense, 199 heterozygous, and 103 homozygous lax, which immediately suggests a ratio of 1:2:1 as a logical theory

to explain the results. Table 6 shows the closeness of fit when the calculated expectancy is compared with the observed numbers on the basis of a one-factor difference. From this table it is seen that P = .90, which indicates that the theory of a one-factor difference is probably correct.

INHERITANCE OF AWNS

The awns of the F_1 plants were of intermediate length, although they resembled more closely the apically-awned parent Both parental types and a group of intermediates were recovered in the F_2 The group of intermediates all segregated in the F_3.

The awn data of the F_3 generation showed segregation into three classes as follows. Awnless, or rather awn-tipped, like the Ridit parent; intermediate; and fully awned, like the Utac parent. These classes were designated as awns 2, 3, and 4, respectively. The plants classified as belonging to awns 2 had short apical awns limited to the upper part of the spike. In awn class 3 the awns extended farther down the spike than in awns 2 and were considerably longer and coarser. In awn class 4 the major portion of the spike was covered with long awns, enough longer than awns 3 to be easily distinguished from them. In the fully-awned group, the lax spikes had visibly longer awns than the dense ones.

TABLE 6. —*Goodness of fit of three groups of F_3 progenies for spike density compared with a 1:2:1 ratio.*

Progeny group	Observed value (O)	Calculated value (C)	O − C	$(O - C)^2$	$\frac{(O - C)^2}{C}$
Homozygous dense.	96	99.5	— 3.5	12.25	.123
Heterozygous .	199	199.0	——	——	——
Homozygous lax.	103	99.5	3.5	12 25	.123

$X^2 = .246$ P = .903

According to recorded F_3 data, there are 100 homozygous awnless, 193 heterozygous segregating for awns 2, 3, and 4, and 105 homozygous fully-awned progenies. This is a close approximation of a 1 : 2 : 1 ratio.

Table 7 gives the three awn classes based on their genotypic differences, their expected ratio, and expected breeding behavior on the basis that there is a difference of one factor.

Table 8 shows the observed and calculated numbers of families and the closeness of fit of the expected to the observed on the basis of a one-factor difference. It is seen that $X^2 = .51$ and P = .7994, which is a very good fit, interpreted to mean that in 80 chances out of 100 a worse fit might occur due to chance alone.

TABLE 7.—*Three awn-class genotypes, their breeding behavior, and the expected ratio on the basis of a one-factor difference*

Awn class	Expected proportions	Genotype	Expected breeding behavior
4	1	AA	Breeding true for awns 4
3	2	Aa	Segregating for awns 2, 3, and 4
2	1	aa	Breeding true for awns 2

TABLE 8.—*Goodness of fit of three awn genotype classes of F_3 progenies when compared with a 1:2:1 ratio which would be expected theoretically with a one-factor difference.*

Progeny group	Observed value (O)	Calculated value (C)	O — C	(O — C)²	$\frac{(O-C)^2}{C}$
Homozygous awns 2 .	100	99.5	— .50	2.50	.0251
Heterozygous awns 2, 3, 4. . . .	193	199.0	+6.00	36.00	.1809
Homozygous awns 4 .	105	99.5	—5.50	30.25	.3040

P = .7994 X^2 = .5100

SOIL HETEROGENEITY

Harris (2) states that, "unless special precautions are taken, irregularities in the field may have greater influence upon the results of an experiment than the factors in crop production which the investigator is seeking to compare."

The Harris method of measuring soil heterogeneity uses the coefficient of correlation r as an index to soil heterogeneity. The correlation between the contiguous parental rows systematically distributed in this cross was so measured. The coefficient of correlation for spike density was $+.218 \pm .103$, which is only a trifle more than double the probable error. The amount to which total variability in mean internode length is dependent upon soil heterogeneity can be determined by squaring r. In this case the variation is found to be about 5%.

Because of the small effect of soil heterogeneity with respect to spike density, the spike density data may be regarded as influenced only in a minor way by the soil heterogeneity.

KERNEL COLOR

In the F_1, all plants had red kernels. In the F_2, 371 plants had red kernels and 29 white. This proportion suggests a 15 red: 1 white ratio. Each F_3 plant in all the progenies was classified as to kernel color. The progenies from the F_2 plants with white kernels bred true in the F_3, while the remaining plants behaved in the following manner: 168 were true-breeding for red grain, 101 were segregating 15 red: 1

white, and 99 were segregating 3 red: 1 white. On the basis of a two-factor difference, the calculated expectancy in the F_3 for each 16 plants is as follows:

True-breeding red grain	7
Segregating 15 red: 1 white	4
Segregating 3 red: 1 white	4
True-breeding white grain	1
Total	16

Table 9 shows the goodness of fit for the color of grain when the calculated numbers in each class are compared with the observed on the basis of a two-factor difference between the two parents. P = .7349 which is a good fit. By chance alone a worse fit might be expected in 73 out of 100 cases.

TABLE 9. *Closeness of fit of four groups as to grain color on a two-factor difference (7:4:4:1 ratio).*

Progeny group	Observed value (O)	Calculated value (C)	O – C	$(O - C)^2$	$\frac{(O - C)^2}{C}$
Homozygous red grain	168	174.125	–6.125	37.5156	.2155
Segregating 15 red: 1 white	101	99.500	–1.500	2.2500	.0226
Segregating 3 red: 1 white	99	99.500	– .500	.2500	.0025
Homozygous white grain	30	24.875	–5.125	26.2650	10.518

$P = .7349 \quad X^2 = 1.2924$

SUMMARY

There were three spike-density groups in the F_3 progenies as follows: Homozygous dense, heterozygous, and homozygous lax. Explained on a one-factor basis, P = .9.

Homozygous and heterozygous groups were readily separated by use of the coefficient of variability which was more than 3 to 10 times as great in the heterozygous progenies as in the homozygous.

The spikes of homozygous dense progenies were more compact than the spikes of the more dense (Utac) parent, and the lax progenies were more lax than the more lax (Ridit) parent. These transgressive segregations, studied statistically, were found to be definite and pronounced, the odds being millions to 1 that they were significant.

The data on awns indicate a one-factor difference, P = .8. In grain color, a two-factor difference satisfactorily explained the data, P=.73.

A correlation between the pairs of parental rows gave a positive r of + .218 ± .103, indicating that soil heterogeneity was not measur-

ably noticeable in this field with respect to spike density. This greatly enhances the validity of the data regarding transgressive segregation.

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A FACTORIAL ANALYSIS OF SOME QUANTITATIVE CHARACTERS IN A CROSS BETWEEN *T. VULGARE* VAR. SONORA AND *T. COMPACTUM* VAR. CLUB C. I. 4534[1]

JOEL WALLACE ELLIOTT[2]

In this paper a factorial analysis relating to spike length of data arising from a cross of Sonora with Club C. I. 4534, and the reciprocal, will be presented.[3] A subsidiary factorial analysis concerning the number of spikelets to the spike will be included.

HISTORICAL REVIEW

Boshnakian (2, page 865)[4] wrote, "If the number of internodes in a population is more or less constant,....the length of the rachis is directly proportional to the average internode length."

[1]Contribution from the Department of Plant Breeding, Cornell University, Ithaca, New York. The original data for this article were presented in a thesis submitted to the Graduate Faculty of Cornell University in partial fulfillment for the degree of doctor of philosophy, January, 1931. Paper No. 185, Department of Plant Breeding. Received for publication January 25, 1932.

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[3]In this paper Sonora refers to *T. vulgare* var. Sonora and Club to *T. compactum* var. Club C. I. 4534.

[4]Reference by number is to "Literature Cited," p. 778.

Since the investigation reported in this paper concerning the number of spikelets or internodes in the cross of Sonora with Club will develop that there was no genetical difference between these two wheats in that character, it appears that in investigating length of spike that the character density will be indirectly analysed also. Thus, a comparison may be made between results to be reported and those of others concerning density.

Many investigations have been made relating to density or the inheritance of lax open heads and short dense heads in wheat. Generally, it has been found that dense or compactum-like heads were dominant over lax heads, or that, while the F_1 generations were intermediate, they were nearer the compactum parent than the lax. In such cases the F_2 segregated approximately in the ratio of three dense headed to one lax headed wheats. Such was found to be the case by Spillman (8), Strampelli (9), Wilson (11), Von Tschermak (10), Nilsson-Ehle (6), Mall (4), Parker (7), Boshnakian (2), Meyer (5), and others. Exceptions to these were obtained by Spillman (8), Biffen (1), and Meyer (5).

In the crosses of Spillman's Little Club X Farquhar, Biffen's Squarehead's Master X Red King, and Meyer's Heils roter glasiger Dickkopt ♀ X griechischer Sammetweizen ♂ and Weisser Frankinsteiner ♀ X Eckendorfer begrannter Dickkopf ♂, the F_1 generations were either intermediate in density between the dense and lax parents or exceeded the latter. In the F_2 generations the lax parents were equaled or transcended, while the dense were not in any case transcended. Here lax heads were dominant over dense heads. Meyer's F_2 intermediate classes of these crosses exhibited segregation among the F_3 with ratios of 15 lax to 1 dense and 3 lax to 1 dense. Biffen's cross of Rivet with Polish represented a *T. turgidum* with *T. polonicum* cross and hence cannot be considered here.

METHODS

During 1928 the parental and F_2 generations were raised. In 1929, from a first planting made April 24, the parental and F_3 generations were obtained, and from a second planting on May 15, the Sonora, F_1, F_2, and F_4 were obtained. Parental, F_1, and F_3 generations had been grown in the greenhouse during the winter of 1928–29.

Crosses of Sonora ♀ with Club ♂ were made during the summer of 1928 in the field and the reciprocal during the spring of 1929 in the greenhouse.

The average spike length per plant was obtained in 1928. In 1929 only the first spike of each plant was measured as correlation studies

made the previous year had indicated the reliability of this method. This was also true for other characters studied. Measurements were taken to the closest millimeter.

SPIKE LENGTHS

In Chart I are presented a series of 10 tables of frequency distribution for spike lengths.

Table 10 gives only the means of 75 different F_3 families grown in 1929. The distributions of these and of the 23 F_4 strains are not included due to lack of space. The mean spike lengths of seven F_3 families from which individual plants were selected to be parents of F_4 strains are presented in Chart V, which also displays the mean spike lengths of the F_4 strains.

THE PARENTAL GENERATION, 1928 AND 1929, ENVIRONMENTAL VARIATION

While the mean spike length of Club in 1929 was .25 ± .07 cm greater than in 1928, that of Sonora from the first planting in 1929 was .72 ± .06 cm shorter than the 1928 Sonora mean. These differences may be observed by comparing Table 1 with Table 2 and Table 3 with Table 4, Chart I. In terms of their respective 1929 means these differences represent an increase of 4.48% for the Club and a decrease of 9.86% for the Sonora. This would suggest that, while Club was affected by environmental influences, it was relatively more stable in spike length than Sonora.

The mean spike length obtained from the second planting of Sonora in 1929 was 1.04 ± .08 cm shorter than that from the first planting of the same variety in the same season. This was 14.20% less than the first mean. Possibly not all of this can be attributed to environmental influences as there was a great difference between the total numbers of the two plantings, 560 for the first and only 90 for the second. This is especially true in view of the similarity of their ranges, as seen in Tables 4 and 5, Chart I. Both plantings were grown in the same field and had only 21 days difference between their planting dates. The first 7 days after the first planting were too cold for growth. While recognizing the possible influence of these various conditions, in order to be conservative, the Club and Sonora means of the first planting will be utilized for comparison with the second as well as the first planting items.

THE F_1 GENERATION GROWN IN THE FIELD, 1929

The F_1 generation of 1929 shown in Table 6 of Chart I, contained only 41 plants which had a range in spike length from 4.6 to 9.2 cm.

CHART I.—*Tables of frequency distribution for spike lengths.*

Class means	Table No. 1	2	3	4	5	6	7	8	9	10
	Club C.I. 4534		Sonora			F_1 1929	F_2 generations		F_2 parents of F_3 lines	F_3 means 1929 (1st)
	1928	1929	1928	1929 (1)	1929 (2)		1928	1929		
2.6	—	—	—	—	—	—	—	2	—	—
.8	—	1	—	—	—	—	—	—	—	—
3.0	—	2	—	—	—	—	—	—	—	—
.2	—	1	—	—	—	—	1	—	—	—
.4	—	—	—	1	1	—	—	3	—	—
.6	—	2	—		—	—	1	6	—	—
.8	1	—	—	—	1	—	—	—	—	—
4.0	1	3	—	1	3	—	2	2	—	—
.2	1	2	—	1	1	—	2	6	—	—
.4	1	2	—	1	2	—	1	6		—
.6	2	6	—	1	5	1	3	11	3	—
.8	5	11	—	5	5	—	5	11	1	3
5.0	5	13	—	3	3	—	8	11	1	3
.2	7	14	1	5	6	1	10	9	2	6
.4	9	16	2	7	3	1	18	13	7	4
.6	6	14	1	7	6	1	11	17	5	7
.8	13	22	1	6	13	1	15	15	3	—
6.0	1	12	3	23	4	1	8	19	1	5
.2	—	9	1	14	6	3	8	18	5	4
.4	—	15	—	31	7	1	12	10	4	11
.6	—	6	2	34	4	4	14	14	1	6
.8	—	7	—	36	2	2	11	18	1	6
7.0	—	2	6	40	4	5	16	14	—	7
.2	—	1	6	59	3	3	20	19	4	3
.4	—	3	11	55	2	7	19	14	3	1
.6	1	—	16	62	2	2	17	16	3	1
.8		—	8	56	4	2	16	8	5	2
8.0		—	8	46	2	—	15	18	4	2
.2	—	—	15	21	—	3	28	13	6	3
.4	—	—	14	22			17	3	1	1
.6	—	—	11	9	—	1	10	10	1	—
.8	—	—	9	5	—	1	21	6	5	—
9.0	—	—	4	7	—	—	11	3	3	—
.2	—	—	2	1	1	1	7	5	2	—
.4	—	—	1	1	—	—	4	3	1	—
.6	—	—	—	—	—	—	3	2	1	—
.8	—	—	3	—	—	—	1	2	—	—
10.0	—	—	1	—	—	—	1	3	—	—
.2	—	—	1	—	—	—	2	—	2	—
.4	—	—	—	—	—	—	—	1	—	—
.6	—	—	—	—	—	—	1	—	—	—
.8	—	—	—	—	—	—	—	—	—	—
11.0	—	—	—	—	—	—	1	—	—	—
.2	—	—	—	—	—	—	—	—	—	—
.4	—	—	—	—	—	—	—	—	—	—
.6	—	—	—	—	—	—	1	—	—	—
Total	53	164	127	560	90	41	341	331	75	75
Mean	5.42	5.67	8.03	7.31	6.27	7.12	7.32	6.68	—	6.48
P. E. of M.	±.06	±.05	±.06	±.03	±.08	±.10	±.05	±.06	—	±.07

as compared with the total first planting parental range of 2.8 to 9.4 cm and the second planting of Sonora of 3.4 to 9.2 cm. The F_1 mean spike length was 7.12 ± .10 cm and was intermediate between the average parental mean of 6.49 cm and the first planting of 1929 Sonora mean of 7.31 ± .03 cm. It exceeded the second planting Sonora mean (6.27 ± .08 cm) of that year. The position of the F_1 range and mean in comparison with those of the parents makes this cross comparable to those reported by Spillman, Biffen, and Meyer in its indication that the vulgare, Sonora in this instance, was at least partially epistatic or dominant to the compactum, Club C. I. 4534 in this case, in spike length. This F_1 thus indicates that no inhibitory factor for spike length was apparent in the factor interaction system.

THE PARENTAL CONTRIBUTIONS

That both 1928 and 1929 F_2 ranges exceeded the grouped parental ranges in their respective years on both the shorter and longer spiked extremities can be seen in Chart I by comparing Table 7 with Tables 1 and 3 and also Table 8 with Tables 2, 4, and 5. Since these F_2 extremes were sufficiently distant from the parental means of the respective years for the plants therein to be genetically different from the parents this indicates more than a mono-factorial interaction to which each parent had contributed. This was corroborated by the F_3 distribution of means having several cases which exceeded the parental means at both extremes, as is shown in Chart I by comparing Table 10 with the means of Tables 2 and 4.

CHART II.—*Calculated F_2 parents compared with actual F_2 parents in various sections of the total F_2 distribution.*

F_2 section inclusive of	3.2 to 5.0	5.2 to 6.0	6.2 to 7.0	7.2 to 8.0	8.2 to 9.0	9.2 to 10.0	10.2 to 11.6	Total
Total F_2 in 1928	23	62	61	87	87	16	5	341
Calculated F_2 parents	5.1	13.6	13.4	19.1	19.1	3.5	1.1	74.9
Actual F_2 parents	5	18	11	19	16	4	2	75.0
Difference of each section	0	+4	—2	0	—3	0	+1	0.0
Difference by halves		+2			— 2			0.0

These results differed from those arising from crosses reported by Spillman, Biffen, and Meyer whose F_1 generations appeared somewhat similar to that of this cross. In none of those were both parents transcended by the F_2 and F_3 generations at both extremes of their frequency curves.

The selection for F_2 parents of F_3 families had been approximately proportional to the total F_2 distribution. This may be observed in Chart II. Here, the F_2 range of Table 7, Chart I, was

divided into eight parts and the observed frequency of each obtained. These frequencies were multiplied by 75/341 to obtain the theoretical number of F_2 parents which would represent each section proportionately. This calculated number was compared with the actual F_2 selections for F_3 families as shown.

The lower half of the F_2 range had two more plants, while the upper half had two less, than the calculated number. That the maximum and minimum extremes of the total F_2 distribution were not represented in the selection nor was each F_2 class proportionately so may be seen by comparing Table 7 with Table 9 in Chart I. However, in general, the behaviour of the observed F_3 generation should have given a fair representation of what might have been expected had all F_2 plants of the 1928 population been planted.

There were nine F_3 families with means within the limits as prescribed by the Club mean plus or minus 3 times its probable error. There was only one family whose mean spike length was longer than this but shorter than the 1929 F_3 class of least frequency, 5.8 cm. This class will be discussed later. These 10 families had F_2 parents which were within the 1928 Club range. It appears that these were recovered Club-like forms. Data concerning them are presented in Chart III, Table 1. The total of these recovered Club-like forms should be corrected due to a disproportionate selection from the F_2 classes of plants used as parents of the F_3 families. The corrected number, about eight, is closer to a 15 to 1 than to a 3 to 1 or 63 to 1 expectancy based on 75 families.

There were five F_3 families which were within the limits as set by the Sonora mean plus or minus 3 times its probable error. Their F_2 parents were within the Sonora range of 1928. These F_3 families are shown in Chart III, Table 2. The corrected number of F_2 within the 1928 Sonora range, which produced F_3 progenies having means such as to classify them as recovered Sonora, was 4.95, or in round numbers, 5. This agrees well with a 15 to 1 expectation, 4.69.

It will be recalled that the extremes of the F_2 distributions and of the distribution of F_3 means indicated more than a mono-factorial interaction to which each parent had contributed. This has now been corroborated by the recovered parental-like families ascertaining that there were two genes concerned in the interaction. Thus each parent contributed one gene. The discrepancy between the F_1 and F_2 means of Tables 6 and 8 in Chart I may be explanied on the basis of sufficiently few genes concerned to allow for a segregation, as expressed by the F_2 phenotypes, which might have caused a dragging effect upon the F_2 mean, causing it to be lower than the F_1 mean.

CHART III.—*Data on spike length of parents compared to parental type F_3 families in 1929.*

Table No.	Family	F_3 means in 1929	F_3 population	F_3 ranges in 1929	F_2 parent in 1928	Corrected number
1	Club C. I. - 4534	5.67 ± .05	164	2.8 to 7.4	5.42 ± .06	
Club type.	d-1-175	5.53 ± .11	40	3.2 to 6.8	5.38	1.10
	d-1- 32	5.55 ± .13	26	3.1 to 6.6	5.50	.57
	c-1- 54	5.56 ± .11	29	3.4 to 6.8	5.84	1.10
	c-1- 26	5.70 ± .09	46	3.6 to 7.8	6.02	1.76
	c-1- 98	5.71 ± .24	14	3.2 to 7.4	6.30	.35
	d-1-162	5.65 ± .15	19	4.6 to 8.4	4.96	1.10
	c-1- 58	5.76 ± .18	13	3.8 to 7.0	5.77	.48
	c-1- 38	5.79 ± .14	34	3.8 to 7.2	5.64	.48
	c-1-124	5.80 ± .14	22	3.4 to 7.4	6.57	.66
	d-1-102	5.88 ± .14	23	3.4 to 7.2	5.49	.57
	Total uncorrected families 9 or 10, corrected families 8.17					
2	Sonora	7.31 ± .03	560	3.4 to 9.4	8.03 ± .06	
Sonora type..	d-1-164	7.25 ± .07	174	2.8 to 10.6	8.39	1.03
	d-1- 44	7.26 ± .07	104	3.6 to 9.6	8.28	1.03
	d-1-130	7.26 ± .21	20	3.8 to 10.0	8.33	1.03
	c-1-121	7.27 ± .12	64	4.4 to 9.4	8.13	.83
	c-1- 76	7.35 ± .08	27	6.0 to 8.2	8.33	1.03
	Total uncorrected families 5, corrected families 4.95					

Expected on 15: 1 hypothesis = 5. Expected on 3: 1 hypothesis = 19

RELATIVE PHENOTYPIC EFFECTS OF THE GENES

That the two genes may not have equal effects upon length of spike was indicated by the general bimodal appearance of the F_2 frequency distributions of both 1928 and 1929 in Chart I, Tables 7 and 8. These had low points of frequency at 6.0 cm for the first year and 5.2 cm for the second. Since the 1928 Club distribution ended at 6.0 cm, which class coincided with the 1928 F_2 low point, it would appear that the Club, or compactum-like segregates, were confined to that section of the F_2 frequency curve up to and including this class. The number of F_2 plants up to and inclusive of class 6.0 was 85 and thus comprised 24.93% of the total 1928 F_2 frequency, or 341. The 3 to 1 ratio suggests that one of the genes, possibly contributed by the Sonora parent, has a greater influence on spike length than the other which may have been brought into the interaction by the Club parent. This assumption was corroborated by the bimodal appearance of the 1929 F_2 frequency curve and its 67 plants which were within its lower section up to and inclusive of the low frequency class, 5.2 cm. These plants were 20.10% of the total number (331), in the 1929 F_2 popu-

lation. This percentage and the bimodal appearance of the curve also indicate greater effects on spike length from one of the genes than from the other.

Further substantiation of this indication, supplied by the two F_2 distributions, may be observed in the frequency distribution of the F_3 means given in Chart I, Table 10. Similar to the F_2 curves this likewise was bimodal. The class of least frequency was at 5.8 cm which contained no F_3 means.[5] The number of families up to this class was 23, or 32% of the total of 75. This approximates a 3 to 1 ratio, considering the small number of families.

Since, as has been shown, each parent contributed one gene to the interaction, it now appears, considering the bimodal frequency curves exhibited by the two F_2 generations and the F_3 means, and the ratios of three long to one short shown by the same, that the Sonora parent brought into the interaction a gene which had a greater lengthening influence upon spike length and which may be denoted as A than did the other which was apparently inherited from Club C. I. 4534 and may be termed B. If XX represents the genic complex which this investigation has been unable to determine, then factorial symbols may be partially applied. They are as follows:

Sonora and recovered Sonora types..............	AAbbXX
Club C. I. 4534 and recovered Club types..........	aaBBXX
Dihybrids, such as F_1..........................	AaBbXX

This does not take into consideration the variability of ranges which these genotypes may have possessed.

Since the F_3 families[5] below the break at 5.8 cm appeared to lack the Sonora or A factor, it is reasonable to assign the genotypes aaBBXX, aaBbXX, and aabbXX to the section of the distribution of F_3 means which was below that class. It may be assumed that the means of those families having the genotypic compositions AabbXX, AaBbXX, and AaBBXX were between the F_3 break, class 5.8 cm, and the Sonora mean less 3 times its probable error. The genotypes AABbXX and AABBXX were possibly represented by the F_3 families having mean spike lengths longer than the Sonora mean.

THE F_4 GENERATION

Seven presumably heterozygous F_3 families were selected from various sections of the F_3 frequency curve with which to test the

[5]Those whose means were less than the low frequency class 5.8 cm in Table 10 of Chart I.

assumption of genotypes by the behaviour of their F_4 progenies. Table 10 in Chart I should be compared with Chart IV. The F_3 parental plants from each family were from various sections of their respective F_3 frequency curves, excepting d–1–56 and c–1–46, and thus the effects of segregation could be observed among the F_4.

Before considering the F_4 generation it is well to recall the relatively stable effect of the gene inherited from the Club parent and the sensitiveness to environmental influences possessed by the gene from Sonora. While the genotypes of the compactum or Club-like F_4 strains may be judged from their means, such is not the case with the vulgare-like strains. Thus, the possible range for the F_4 recovered Sonora strains might be from 7.31, the 1929 first Sonora mean, to 6.27, the 1929 second planting Sonora mean. In order to be conservative, the writer will utilize the Club and Sonora means of the first planting when making comparisons.

The F_3 family, d–1–9, whose field F_3 mean was less than that of Club C. I. 4534 appeared possibly heterozygous for the B factor, aaBbXX. If such was the case, then segregation should have been evident among its F_4 progenies suggestive of the genotypes aabbXX, aaBbXX, and aaBBXX. Indeed, on the basis of statistically significant similarities and differences, the d–1–9 F_4 strains 8 and 18, with means of $5.70 \pm .14$ and $5.39 \pm .12$, were recovered Club types, aaBBXX. The progenies 9 and 4, having as means $5.00 \pm .11$ and $4.77 \pm .08$, probably represented aaBbXX in genotype. Finally, strain 15, whose mean was $4.28 \pm .14$, represented the homozygous recessive aabbXX. (For data on this family, see Chart IV.) The expected segregation was realized, thus giving evidence that the gene inherited from the Sonora parent was not present in those F_3 families with means below the break in the F_3 distribution. Only the gene from the Club parent was represented in these strains.

If the section of the frequency curve of F_3 means between its break and the Sonora mean contained families of the genotypes AabbXX or AaBbXX, then families c–1–39, c–1–92, and c–1–140 should have had some F_4 strains of the recessive genotype. Furthermore, certain progenies similar to Club and others with longer spikes than Sonora should have arisen.

The means of the F_4 strains c–1–39–19, c–1–92–2, and c–1–140–1 were $4.44 \pm .19$, $4.24 \pm .10$, and $4.42 \pm .22$ cm, respectively, and their F_3 parental lengths of spikes 4.3, 4.1, and 4.6 cm, which compare well for fixity of type. Furthermore, c–1–92–2 had the shortest mean spike length in the whole series of experiments. The three means appeared significantly similar to each other and to the mean of

d-1-9-15 which has been shown to be recessive in both genes. Thus, these F_4 strains were representative of the double recessive genotype aabbXX.

The Club mean, 5.67 ± .05, was similar to that of c-1-92-1, 5.67 ± .11. Although the mean of c-1-140-14, 7.65 ± .28, did not significantly exceed that of the Sonora from the first planting ,7.31 ± .03, it did exceed that of Sonora from the second planting, 6.27 ± .08, which was sown at the same time as the F_4 generation.

Segregation, as expressed by the F_4 generation, fulfilled the expectation of that portion of the frequency curve of F_3 means between its break and the Sonora mean, less 3 times its probable error. Indeed the genotypes AabbXX and AaBbXX probably apply to this section of the curve.

Since 7.60 ± .11, the field F_3 mean spike length of d-1-66, represented that section of the F_3 distribution which was just above the mean of Sonora, plus 3 times its probable error, this F_3 family possibly represents the genotype AABbXX. If this assumption is correct segregation should have been evidenced among the F_4 strains by having the shortest mean similar to Sonora and others significantly longer than the mean of that parent. The F_3 plant which had the shortest spike gave an F_4 progeny whose mean was 6.95 ± .13 cm. This mean was smilar to that of the Sonora parent. From the longest F_3 individual an F_4 strain was grown whose mean was 8.00 ± .13. The difference between this and the Sonora mean was .69 ± .13 cm. Thus, F_4 strains with longest and shortest spikes fulfilled the expectation and the assumption is correct that F_3 means slightly longer than the Sonora mean, plus 3 times its probable error, represented the genotype AABbXX. Only this and AABBXX could have been the genotypes whose F_3 means were greater than the mean of the first planting Sonora parent.

The 23 F_4 strains fulfilled the requirements of the test to verify the assumption that certain genotypes could be assigned to certain sections of the F_3 distribution of means when the assignment was based upon a bifactorial hypothesis in which a greater lengthening of the spike was attributed to the gene inherited from the Sorona parent than to the one from the Club C. I. 4534.

NUMBER OF SPIKELETS

As the number of spikelets on a spike is one more than the number of internodes, in studying this character one is indirectly investigating the number of internodes. The analysis for this character will be presented in summary form only.

CHART IV.—*The F_4 means of 1929 arranged phenotypically and genotypically in relation to their 1929 F_3 means, phenotypic and genotypic groups, data from the greenhouse F_3 generation and F_2 of 1928 also given.*

F_3 phenotypic group and possible genotypes of F_3	1929 field F_3 families and means*	Ranges and means of F_3 in greenhouse	F_2 parental plant of 1928	1929 field F_4 means and greenhouse F_3 parental plants†				
				Compactum like			Vulgare like	
				Possibly recessive	Significantly less than Club	Similar to Club C. I. 4534	Not greater than Sonora	Greater than Sonora
Compactum-like... less than Club .. mean less 3 (P. E.), aaBbXX....	d-1-56 5.25±.10	3.4 — 5.6 4.57	4.75	or	4.57±.12 (4.4) 5.00±.12 (4.5)			
	d-1-9 5.25±.10	4.2 — 10.2 5.88	5.72	4.28±.14 (4.2)	4.77±.08 (5.1) 5.00±.11 (5.6)	5.39±.12 (5.1) 5.70±.14 (10.2)		
Vulgare-like from F_3 break to Sonora mean less 3 times P. E., AabbXX, AaBbXX, or AaBBXX	c-1-39 6.17±.17	4.3 — 9.6 7.46	8.29	4.44±.19 (4.3)			6.30±.22 (8.3) 6.69±.17 (6.8) 7.01±.15 (9.1)	

	c-1-92	4.1 — 9.5	—	4.24±.10	—	—	6.25±.14	—
	6.51±.17	7.28	5.70	(4.1)	—	—	(7.0)	—
	—	—	—	—	—	5.67±.11	—	—
	—	—	—	—	—	(7.5)	—	—
	c-1-140	3.6 — 9.6	—	4.42±.22	—	—	6.13±.26	—
	6.59±.20	7.59	8.80	(4.6)	—	—	(8.0)	—
	—	—	—	—	—	—	—	7.65±.28
	—	—	—	—	—	—	—	(8.1)
	—	—	—	—	—	—	6.68±.17	—
	—	—	—	—	—	—	(8.6)	—
	c-1-46	6.6 — 9.4	—	—	—	—	6.76±.13	—
	7.05±.10	8.73	8.79	—	—	—	(8.7)	—
	—	—	—	—	—	—	7.09±.13	—
	—	—	—	—	—	—	(8.5)	—
Greater than Sonora mean plus 3 times P. E., AABbXX . .	—	—	—	—	—	—	6.95±.13	—
	—	—	—	—	—	—	(7.9)	—
	d-1-66	7.4 — 9.5	9.20	—	—	—	7.57±.13	or
	7.60±.11	8.56	—	—	—	—	(8.5)	—
	—	—	—	—	—	—	—	8.00±.13
	—	—	—	—	—	—	—	(9.5)

*The field F_3 of 1929 and greenhouse F_3 were sister plants obtained by dividing the seed of each F_2 mother plant.
†Figures in parenthesis below the F_4 means signify the greenhouse F_3 parental plant's value of that F_4 strain.

CHART V.—*Tables showing number of spikelets per spike; frequency distributions in 1928 and 1929 for parents, F_1, F_2, F_2 parents of F_3, and F_3 means.*

Generation	Club C. I. 4534		Sonora			F_1	F_2 generation		F_2 parents	F_3 families
Year grown	1928	1929	1928	1929 (1st)	1929 (2nd)	1929	1928	1929	1928	Means of 1929
Table No.	1	2	3	4	5	6	7	8	9	10
Number of spikelets										
8	—	—	—	—	—	—	—	1	—	—
9	—	—	—	—	1	—	—	1	—	—
10	—	—	—	—	4	—	6	2	—	—
11	—	—	—	3	4	—	2	5	—	—
12	1	1	1	3	10	—	8	5	—	—
13	—	1	7	7	6	—	19	8	4	1
14	2	15	4	18	10	3	18	11	1	6
15	1	15	10	53	16	2	45	24	9	19
16	8	25	19	111	15	5	72	18	15	37
17	10	29	21	152	21	4	72	43	19	12
18	11	29	27	129	4	8	53	28	14	—
19	13	34	24	76	1	4	27	51	7	—
20	2	10	12	9	1	4	12	50	5	—
21	3	5	—	—	—	7	3	33	1	—
22	1	1	—	—	—	5	1	23	—	—
23	1	—	—	—	—	—	—	14	—	—
24	—	—	—	—	—	—	—	10	—	—
25	—	—	—	—	—	—	—	7	—	—
26	—	—	—	—	—	—	—	2	—	—
Total	53	165	125	561	93	42	338	336	75	75
Mean	17.85	16.26	16.22	15.96	14.83	18.50	16.33	18.60	16.93	15.92
P. E. M.	±.18	±.10	±.12	±.04	±.16	±.25	±.08	±.12	±.13	±.07

The 10 tables in Chart V give the frequency distributions, together with the total frequencies, the means, and the probable errors of the means in the years 1928 and 1929 for the parents, the F_1 generation for 1929 only, the two complete F_2 populations, the F_2 plants of 1928 from which the F_3 progenies of 1929 were grown, and the means of the F_3 progenies. All were grown in the field. Due to lack of space the frequency distributions for the F_3 families and data upon the F_4 generation are not presented in this paper.

The similarity between the means in 1928 of Sonora and the F_2 generation, Tables 3 and 7, Chart V, and in 1929 between those of Sonora and Club, Tables 2 and 4, Chart V, furnished a basis for the hypothesis that there was no genetical difference between the two parents concerning the number of spikelets borne by a spike.

In contrast with the spread of over nine classes exhibited by the selections of F_2 plants, which were parents of F_3 progenies, the means of their F_3 populations ranged only from 13 to 17 spikelets per spike, inclusive. The spread had contracted to five classes. In Chart V, Tables 7 and 9 should be compared with Table 10.

The coefficient of correlation, $.162 \pm .076$, obtained by comparing the values of the selected F_2 parental plants with their F_3 means, is very low and indicates an association of little or no significance.

The relations which F_4 means bore to one another in the number of spikelets per spike could not be foretold from the relative number of spikelets borne by their F_3 parental plants. Thus, it is safe to conclude, in consideration of results previously presented, that there is no genetical difference capable of being measured between Club C. I. 4534 and Sonora with respect to the number of spikelets per spike.

SUMMARY

The investigation concerning spike length indirectly dealt with density for it has been established that there is no genetical difference between Club C. I. 4534 and Sonora with respect to the number of spikelets or internodes to the spike. The results obtained from the parental, F_1, F_2, F_3, and F_4 generations show that the spike length interaction was bifactorial in nature. One gene, inherited from the Sonora parent, exerted a greater influence, while the other, from the Club parent, seems to have had a less marked effect upon the length of spike. The presence of a shortening, or length inhibiting gene, was not apparent. The fact that each parent contributed to the interaction a gene affecting spike length which the other did not possess, together with the apparent absence of a length-inhibiting gene, caused

the results to be unique and different from those previously reported by other investigators whose researches involved a cross between compactum and vulgare types of wheat.

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THE EFFECT OF BUNT ON YIELD OF WHEAT[1]

H. H. FLOR, E. F. GAINES, and W. K. SMITH[2]

Bunt or stinking smut is the most destructive disease of wheat in the Pacific Northwest. Each year during the past decade from one-fourth to two-thirds of the cars arriving at northwest terminal markets have graded smutty. Losses due to bunt are fourfold, *viz.*, (a) dockage, because the smut on the sound kernels reduces the commer-

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cial value of the crop; (b) the expense of seed treatment in order to prevent heavier losses; (c) reduction in yield because of the production of bunt balls instead of wheat kernels; and (d) the detrimental effects of bunt infection of plants which do not show the typical external symptoms of the disease.

It is difficult to arrive at an approximate figure in estimating loss due to bunt. Dockage and the cost of seed treatment can be determined most accurately, but even these estimates are only approximately correct. The buyer at the primary market seldom makes the proper dockage as he has no accurate way of determining what dockage he will receive at the terminal market. Frequently, wheat from smutty and smut-free fields is mixed before shipping and the mixture is graded smutty at the terminal. Thus, both the grower of smutty and smut-free wheat are penalized.

The cost of seed treatment is easily determined, but the injurious effect of certain treatments, such as those with formaldehyde and copper sulfate, on germination and stand is often difficult to estimate. It generally has been assumed that yield is inversely proportional to percentage of bunted heads, but little accurate data are available on this point.

Heald and Gaines (7)[1] analyzed yield tests made over a period of years and found that a difference of 25.8% of smutted heads made a difference of 23% in yield. Details of the tests were not given, but in order to arrive at their basis for comparison, yields from tests having from 1 to 30% smutted heads were compared with those having from 31 to 71% smut. Evidently their results are applicable only to severe infestations of susceptible varieties. Wheat varieties are known to respond differently to bunt infection (2, 9) so it is possible that results obtained with one variety or with a group of varieties can not be promiscuously applied to all varieties. Little evidence, except observational (1, 11) is available on the effect of bunt infection on yield due to effects other than smutting the head.

MATERIALS AND METHODS

In order to determine the effect of bunt infection on yield, three varieties of winter wheat, differing in their susceptibility, were tested. These varieties were Hybrid 128 (C. I. No. 4512), susceptible; Turkey (C.I. No. 6175), moderately susceptible; and Ridit (C.I. No. 6703), resistant. Heald (6) and Mackie and Briggs (8) have shown that, within limits, percentage of bunt is correlated with spore load and that 1 gram of ground smut per 100 grams of seed is sufficient to

[1]Reference by number is to "Literature Cited," p. 784.

produce maximum infection. In order to obtain variations in the percentage of smut, the following proportions of freshly ground smut to seed were used: 1:100, 1:250, 1:400, 1:1,000, 1:2,500, and uninoculated seed. The varieties were grown in quadruplicate plats of three rod rows each, arranged in the Latin square system, in the agronomy nursery at Pullman, Wash., during the 1929–30 season. The inoculum consisted of equal parts by weight of Gaines' seven physiologic forms (7). The center row of each plat was harvested and, before it was threshed, counts were made of the number of bunted and sound heads in each row.

RESULTS

Although the utmost care was exercised to control external factors and to have the amount of inoculum applied to the seed as the only variable, other factors crept in. There was a slight amount of washing and winter-killing. Birds also caused some injury before harvest. While these factors undoubtedly accounted for some of the discrepancies in the results, they did not seriously affect the test as a whole.

The effect of spore load on percentage of smut and yield, together with the effect of variation in percentage of smut on yield, is given in Table 1

Hybrid 128 was susceptible to all the seven forms of bunt which composed the inoculum, including form 1 of *Tilletia tritici*. This is the form most prevalent in the Pacific Northwest (2). Turkey was resistant to this form, but susceptible to five of the others, while Ridit was resistant to all the forms used. Apparently there was a severe soil infestation of form 1, as the uninoculated seed of Hybrid 128 produced 32% smutted heads. Soil infestation with the other forms was light, as Turkey had but 1.2% smut from the uninoculated seed. The heavy soil infestation interfered with securing a gradation of smut in Hybrid 128. The smut in Turkey and Ridit varied more directly with the amount of inoculum.

Although the heavy soil infestation prevented securing as wide a range in percentage of smut and in yield in Hybrid 128 as was desired, the results indicate that percentage of smut was inversely correlated with yield, the coefficient of correlation being -0.81 ± 0.05. There was considerable irregularity in the results in this series. All inoculations except the 1:250 reduced yield more than appeared justified by the percentage of smutted heads. For the test with Hybrid 128 as a whole, an increase of 16.2% of smut in plats planted with inoculated seed caused a reduction of 20.5% in yield.

The test with Turkey wheat was consistent in that the amount of smut increased with the spore load, and reduction of yield was roughly

proportional to the percentage of smut. An average increase of 30.3% of bunted heads caused a reduction of 23.1% in yield and the coefficient of correlation between percentage of smut and yield was —0.86 ± 0.04, which is very high.

TABLE 1.—*The effect of the percentage of bunt on yield of the wheat varieties Hybrid 128 (C. I. No. 4512), Turkey (C. I. No. 6175), and Ridit (C. I. No. 6703), Pullman, Wash., 1929-30.*

Grams of inoculum per 100 grams of seed	Smutted heads, %	Acre yield, bu.	Variation in smut from uninoculated seed, %	Variation in yield from uninoculated seed, %	Coefficient of correlation between percentage of smut and yield
			Hybrid 128		
1.0	77±0.52	12.2±0.75	+45	—58.4	
0.4	55±1.77	24.4±0.69	+23	-17.0	
0.25	44±1.00	23.5±0.85	+12	-20.0	
0.1	36±1.26	23.2±1.54	+ 4	-21.1	
0.4	29±2.79	33.5±1.14	— 3	+14.0	
0.00	32±0.83	29.4±1.56	0	0.0	—0.81±0.05
Average	------	------	+16.2	20.5	
			Turkey		
1.0	52±3.31	17.6±1.68	+50.8	-44.4	
0.4	46±2.21	22.0±2.17	+44.8	30.4	
0.25	34±1.19	24.3±1.92	+32.8	—23.4	
0.1	16.2±1.89	27.3±0.50	+15.0	—13.6	
0.04	9.2±1.13	30.4±1.32	+ 8.0	- 3.8	
0.0	1.2±0.35	31.6±0.90	0.0	0.0	—0.86±0.04
Average	- - -	----	+30.3	—23.1	
			Ridit		
1.0	1.4±0.20	28.2±1.73	+ 1.35	—16.1	
0.4	1.4±0.21	28.5±2.23	+ 1.35	—15.2	
0.25	1.3±0.23	28.2±1.56	+ 1.25	—16.1	
0.1	1.3±0.24	31.3±2.02	+ 1.25	— 6.8	
0.04	0.5±0.12	32.8±1.16	+ 0.45	— 2.4	
0.00	0.05±0.02	33.6±0.86	0.00	0.00	—0.60±0.09
Average	----	----	+ 1.13	—11.3	

Ridit was resistant to all the forms of bunt used as inoculum and consequently even the heaviest dose gave but little smut. The yield was affected out of proportion to the amount of smut. This effect was especially noticeable with the heavier inoculations and, for the test as a whole, the plats planted with inoculated seed averaged 1.13% more bunt and yielded 11.3% less than the uninoculated planting. The coefficient of correlation between smut and yield was lower than that for the other varieties, being —0.60 ± 0.09.

DISCUSSION

It is known that wheat varieties respond differently to bunt infection under different environmental conditions. For instance, Hope,

which, up to the present time, has been very resistant to all forms of bunt when grown as a spring wheat, was found by Gaines and Smith (5) to possess only slight resistance to the seven forms tested when grown as a winter wheat. Faris (3) found that the optimum temperatures for infection of Dawson and Red Fife by *T. levis*, was lower than that for Marquis. In addition to being influenced by environmental conditions, the reaction of the wheat variety may be affected by the physiologic form used as inoculum. Smith (10) found that when Martin wheat (C.I. 4463) was infected with one form of *Tilletia tritici*, the smutted heads were very long and narrow and the bunt balls dwarfed, seldom being much larger than a pinhead; while with another form of *T. tritici* the smutted heads of this variety were normal and had large bunt balls. Rodenhiser (9) reports that he found greaterr elative differences in length of culms of wheat plants infected with two different forms of *T. tritici* than between the two species *T. levis* and *T. tritici*.

It has been shown that certain wheat varieties react differently when infected with the various physiologic forms of the bunt organisms and under different environmental conditions. Consequently, results on the effect of bunt infection on yield obtained under one set of conditions may not be the same as would have been obtained under another. As these tests were conducted in the winter wheat area of the Pacific Northwest and the forms of bunt used were those known to be most prevalent and widely distributed in this region, they are regarded as being rather typical.

In view of the difference in varietal response to environmental conditions and to the various physiologic forms, it was not surprising to find that considerable difference existed between the three varieties tested in the relation of percentage of bunt to yield reduction. With varieties that were susceptible to the forms of bunt used as inoculum and exhibited, no marked morphological reaction, such as failure to head and sterility of spikelets, the percentage of smut in the crop appeared to be a fair criterion to reduction in yield. However, it is not an exact measure of loss. In these tests the reduction in yield of Hybrid 128 was slightly greater than the increase in percentage of smut. This is difficult to account for as there is no apparent tendency for infected plants of this variety to produce sterile heads or culms which fail to head. On the other hand, the reduction in yield of Turkey was considerably less than the increase in percentage of smut. Among the possible explanations for this are (a) the ability of partially smutted plants to divert food materials from infected to non-infected culms, (b) the stunting and debility of infected plants so that the non-

infected ones can better utilize environmental conditions favoring growth, and (c) the production of sound kernels in partially smutted heads.

A comparison with the analysis of tests made by Heald and Gaines (7) is of interest. These authors found that an increase of 25.8% in smut caused a reduction of 23% in yield. In the tests reported upon in this paper, an average increase of 23.2% in smut with Hybrid 128 and Turkey, which show no marked morphological response indicative of resistance to the bunt forms used as inoculum, caused a reduction in yield of 21.8%.

Ridit was resistant to all forms of bunt used in these tests. An increase in the amount of inoculum resulted in a slight increase in the percentage of smutted heads and a disproportionate reduction in yield. An explanation of this may lie in the nature of resistance in Ridit. The forms used in this test caused the heads of infected plants to become distorted. Seldom was a head produced which was normally smutted, i.e., all the kernels replaced by bunt balls. Many of the infected heads consisted of two or three bunt balls, a few sound or partially smutted kernels, with the remainder of the head sterile. Other heads were produced which had one or more apparently sterile spikelets in which the rudiments of bunt balls could sometimes be found by careful examination. Sometimes culms of infected Ridit plants were dwarfed and failed to head. All of these symptoms of resistance may account for the excessive reduction in yield obtained with the heavily inoculated Ridit seed. It is possible that different results might be obtained with other forms of bunt to which Ridit is more susceptible.

SUMMARY

The effect of the spore load and the percentage of smutted heads in the crop on yield was tested at Pullman, Wash., during the season of 1929-30, using Hybrid 128 (C.I. No. 4512), a susceptible variety; Turkey (C.I. No. 6175), a moderately susceptible variety; and Ridit (C.I. No. 6703), a resistant variety.

The effect of percentage of bunt on yield varied with the variety. An average increase of 16.2% of bunt with Hybrid 128 caused a reduction of 20.5% in yield, while with Turkey an increase of 30.3% of bunt resulted in a 23.1% reduction in yield. With Ridit an average increase of 1.13% of bunted heads resulted in a reduction of 11.3% in yield This may, in part, be accounted for by the morphological reactions of the Ridit plants to smut infection, such as dwarfing of the culms, failure to head, and distortion and partial sterility of in fected heads.

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NATURAL CROSSING IN OATS AT MORGANTOWN, WEST VIRGINIA[1]

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Natural crossing in oats has been reported by investigators from several places in the United States. Experimental evidence obtained at the West Virginia Agricultural Experiment Station[3] indicated a difference between *Avena sativa* and *A. byzantina* in regard to the number of natural hybrids produced. During 1923–25, a total of 7,742 plants, representing six common varieties of *A. sativa*, were grown under conditions that would permit the detection of natural hybrids, and one such plant was observed. When 1,708 plants belonging to the *A. byzantina* species (Fulghum variety) were grown under similar conditions, seven natural crosses were found. This represents a percentage of 0.41 for *A. byzantina* as compared to 0.013

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[3]GARBER, R. J., and QUISENBERRY, K. S. Natural crossing in oats at Morgantown. West Virginia. Jour. Amer. Soc. Agron., 19: 191–197. 1927.

% for the *A. sativa* group. The data presented in the present paper were obtained from further studies with *A. byzantina* to determine, if possible, the cause for such a high differential rate of natural crossing within the two species.

The general plan of procedure was similar to that reported previously and will not be described in detail at this time. The study was confined to 15 Fulghum selections which were interplanted with V.P.I. No 1, a black-seeded variety. Due to the differential ripening dates between Fulghum and V. P. I., it was found necessary to make two different plantings of the Fulghum selections. The plants tested in the succeeding generation were those coming from the replications that flowered at approximately the same date.

A random sample was taken from 50 Fulghum plants that had been grown adjacent to the black-seeded variety. The seeds constituting this sample were separated into primary, secondary, and tertiary classes and planted in such a manner that individual plant observations could be made. The number of natural hybrids that were produced during 1929 and 1930 seasons are presented in Table 1.

TABLE 1.—*Natural hybrids observed among plants from the different classes of seeds of Fulghum oats grown during 1929 and 1930.*

Seed class	1929			1930		
	No. of white-seeded plants	No. of black-seeded plants	Percent of black-seeded plants	No. of white-seeded plants	No. of black-seeded plants	Percent of black-seeded plants
Primary ...	2,118	7	0 33	3,125	5	0.16
Secondary..	2,177	24	1.09	2,968	21	0.70
Tertiary ..	544	1	0.18	932	3	0.32
Total	4,839	32	0.66	7,025	29	0.41

There were seven black-seeded plants or 0.33%, obtained from a total of 2,125 primary seeds in 1929. The 2,201 secondary seeds produced over three times as many black-seeded plants, or 1.09%. On the other hand, there was but one black-seeded form observed among the plants grown from the 545 tertiary seeds. This indicates only 0.18% natural crossing. Subsequent tests of these black-seeded plants showed that all but one were of hybrid origin. The amount of natural crossing observed was 0.66% for a total population of 4,871 plants. The most interesting feature of the data is the relatively large amount of natural crossing observed in the secondary florets.

The data obtained in 1930 agree very well with the observations made in 1929. The amount of natural crossing found in the secondary

florets is over twice as large as for either the primary or tertiary classes. The amount of crossing observed in the tertiary is greater than in the primary florets, which is directly opposite to that found in 1929. The total amount of natural crossing for 1930 was 0.41%. This is somewhat less than the average for 1929 but in close agreement with the average observed for the period of 1923–25 and reported previously.

Evidence presented in this paper indicates that the extent of natural crossing in Fulghum oats (*A. byzantina*) is somewhat dependent on position of the floret in the spikelet. The greatest number of natural hybrids were found among plants coming from secondary seeds.

THE DISTRIBUTION AND ADAPTATION OF *POA BULBOSA* IN THE UNITED STATES AND IN FOREIGN COUNTRIES[1]

H. A. Schoth and Morris Halperin[2]

In the course of studies and observations concerning *Poa bulbosa* described separately (2, 3)[3] it became evident that this grass is characterized by extensive versatility in Europe, Asia, and Africa and in the Pacific Northwest of the United States. Inasmuch as most of the published information is distributed in a large number of European botanical works, it has seemed well to assemble those data to accompany the American data in this report.

The specific conditions mentioned for the occurrence of *P. bulbosa* in the literature reviewed by Halperin (2, 3) include dry soils, sand or sandy soils, roadsides, glaciers, infertile, rocky, and lime soils; open sunlight and forests; elevations from sea-level to 7,000 feet; and cultivated fields.

Rouy (8), Vilmorin (10), and Knoche (5) also report *P. bulbosa* in several of the above-mentioned environmental conditions. Vilmorin (10) and Knoche (5) state that this grass is found in shade.

Data regarding *P. bulbosa* on Szik (alkali) soils in Hungary are quoted as follows from Sigmond (9):

"The plants of Szik prairies have accommodated themselves to the

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[3]Reference by number is to "Literature Cited," p. 793.

arid climate of our Plain, especially to the distribution of the precipitation. The spring flora is supported by the winter precipitation and by the spring rains, and it consists for the most part of early-growing annual plants which come to seed by the end of May or June. During this period *Poa bulbosa* is flourishing already in April. This plant persists as a typical prairie plant amidst the earlier-wilting *Festuca pseudovina*, and it can exist alone on Szik spots, although it is not a halophyte Its short growth is totally wilted by the end of May, but it is a favorite goose and sheep pasture before it is wilted. The growth of *Poa bulbosa* is afterwards displaced by *Matricaria chamomilla*."

Kennedy (4) reports the observations of Korovin (7) to the effect that *P. bulbosa* constitutes 50% of the vegetation over large areas in Turkestan which receive approximately 10 inches of rainfall annually.

Bentham and Hooker (1) state that *P. bulbosa* occurs in temperate and southern Europe and across Russian Asia, northward into Southern Scandinavia. Koch (6) and Rouy (8) report this grass as occurring all over Europe, Asia, and Africa Vinall and Westover (11) report that *P. bulbosa* (apparently var *vivipara*) is now widely distributed over nearly all the temperate and sub-tropical regions of the world, and that it has been reported from England, Germany, France, Italy, Russia, Algeria, Afghanistan, India, South Africa, and South Australia. Data collected by the junior author show the occurrence of the proliferated form in the following additional countries: Armenia Austria, Belgium, Canada, China, Greece, Hungary, India, Morocco, Sweden, Switzerland, Syria, and Turkey.

OBSERVATIONS IN THE UNITED STATES

In this section of the report will be described the writers' observations of *P. bulbosa* (chiefly var. *vivipara*) growing in various environmental conditions in the Pacific Northwest

The senior author's observations on *P. bulbosa* began in 1915, when a small planting of bulblets[4] secured from the Capitol Grounds, Richmond, Virginia, through Mr. Lyman Carrier, at that time connected with the Office of Forage Crop Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, was made at the Oregon Experiment Station, Corvallis. This planting has produced panicles of the unproliferated form at the Oregon Experiment Station continually since that date. Plantings of the Virginia strain made at

[4]Agricultural plantings of the grass are made chiefly with bulbils, which are the proliferated plants formed in the inflorescence, and partly with bulblets which are swollen structures at the base of the stem. Under both natural and agricultural conditions this grass usually reproduces by both bulbils and bulblets. True seeds (caryopses) of *P. bulbosa* are at present unknown.

Arlington Farm, Va., although largely of the unproliferated form, have shown a small percentage of panicles of the proliferated form.

The proliferated form was first seen in 1916, when a specimen identified by the senior author as *Poa bulbosa* L. var. *vivipara* Koel. was sent to the Oregon Experiment Station from Ashland, Oregon, by a Mr. Shepherd. This is the first recorded occurrence of this form of *P. bulbosa* on the Pacific Coast. At that time, according to Mr. Shepherd, there were only a few plants of this grass, growing in adobe soil at the edge of an alfalfa field in the vicinity of Ashland, Oregon; and he found no others in adjoining sections of the Rogue River Valley. Whether or not this small area was the place of introduction and the original source of the present areas on which this grass is now growing has not yet been determined.

Within a few years after the original discovery of the plants on the Pacific Coast, a considerable spread of the grass was noted. Since 1925, plants in various numbers, chiefly of the proliferated form, have been growing on a wide range of soil conditions and under many different conditions of moisture, temperature, altitude, plant competition, and exposure.

The largest and most successful areas of *P. bulbosa* at present are in the Rogue River Valley of Oregon For the most part, this grass grows there on black adobe soils, although it thrives on lighter soils also. In the Willamette Valley of Oregon small plantings of *P. bulbosa* are now growing on sandy loam soils, on clay loam soils of medium heavy texture, and on hill land soils. In the coast sections of Oregon and Washington, *P. bulbosa* is growing on hill lands. These lands are of a medium, clay loam character and usually quite loose and friable. In the drier sections east of the Cascade Mountains, small plantings of the bulbils have been made on light, semi-sandy soils, usually considered quite satisfactory for wheat production and on thin, rocky, drier soils not adapted to grain growing.

Because of the almost exclusive winter-growing habits of this grass, winter moisture is absolutely necessary for successful growth. In some of the irrigated sections the natural rainfall may be augmented to some extent by small early fall irrigations to give the plants an earlier start in making winter growth. In practically all of the sections where this grass is now growing in the Pacific Northwest, west of the Cascade Mountains, there is ample natural moisture for its continuous growth during the winter months. East of the Cascade Mountains, moisture conditions are very variable; and during some years, winter moisture may be so limited as to permit very little growth of the plants. Bulbous bluegrass is now growing under conditions where the winter rainfall varies from 3 to 50 inches. The

amount of moisture available during the growing season is usually directly indicative of the amount of growth the grass makes in regions where it is adapted. In situations exposed to strong winds, especially in sections where the winter moisture is low, *P. bulbosa* makes small growth.

The establishment and maintenance of stands of *P. bulbosa* are generally adversely affected by excessive amounts of moisture in the soil during either winter or summer months. An excess of soil-moisture during the winter reduces growth and may cause the decay of roots and bulblets. Prolonged periods of high soil temperatures apparently destroy the vitality of the bulblets as some of the plantings in partial shade at the Florida Agricultural Experiment Station survived two or three seasons, while those planted in the open failed to grow again in the fall.

In the agricultural and grazing districts west of the Cascade Mountains in Oregon and Washington, winter temperatures are usually mild. Periods of freezing weather occur every winter, but they are generally of short duration and temperatures seldom go below 15°F. The growth of the bulbous bluegrass is, therefore, very seldom checked. East of the Cascade Mountains temperatures quite often drop below the zero point during the winter months. Zero temperatures stop the growth of *P. bulbosa* but apparently do no permanent injury. In Wasco County, Oregon, east of the Cascade Mountains, it has survived the winters and spread quite rapidly.

The present altitude range under which *P. bulbosa* is growing in most places in Oregon and Washington has, for the most part, a maximum elevation of about 1,500 feet. The lower altitudes in this territory are, in general, better supplied with natural winter moisture, and the temperature is more favorable to winter growth.

In the Rogue River Valley of Oregon, this grass is being grown under cultivation with alfalfa (*Medicago sativa*) with which it associates very successfully. There seems to be a rather direct positive growth correlation between the two plants, competition between them being apparently only slight. The bulbous bluegrass makes a heavy winter growth, the two plants together make a heavy spring growth, and the alfalfa alone makes a heavy summer and early fall growth. In general, the most successful stands of *P. bulbosa* are those found in alfalfa fields. This method of culture is being started in the Willamette Valley of Oregon also.

P. bulbosa, because of its heavy sod-forming and winter-growing habits, seems to be very effective in preventing the seedling growth of some annual plants. In alfalfa fields quite heavily infested with various weeds, especially *Bromus tectorum*, *Bromus rigidus*, and *Festuca*

myuros, the establishment of stands of *P. bulbosa* has, after 2 or 3 years, eliminated practically all of this weedy growth. It is not very effective in combating perennial plants because of their usually greater vigor and often continuous growth throughout the year.

The most thrifty growth of this grass is generally made under open conditions, but some excellent stands have been observed in the shade of oak and pine trees. The growth under oak trees is in general better than that under pines, apparently because of the increased amount of light during the winter or active growing season of the grass. In dense shade, as on the fern lands in the Coast section, growth has been comparatively small, attributable perhaps not only to the almost continuous shade, but also to the severe competition of various perennial plants, especially the Western bracken fern, *Pteridium aquilinum pubescens.*

Kennedy and Madson (4) were the first observers of plants of *P. bulbosa* var *vivipara* in California. They found the plants growing at the edge of an alfalfa field near Escalon.

The junior writer's first observations were made in May, 1930, in northern California and southern Oregon On land immediately adjoining the railroad station at Montague, Siskiyou County, California, bulbous bluegrass, the proliferated form, was an invading species. It had spread to this area apparently from a planting made in the fall of 1928 a few hundred feet away Near Yreka, about 5 miles from the Montague locality, this grass covered a small area in dense shade under an oak, constituting practically a 100% stand. In several other places in the same locality, plantings of *P. bulbosa* var. *vivipara* have usually resulted in heavy, practically pure stands under conditions of dense shade; while in immediately adjoining areas where bulbous bluegrass has not been sown, there were many plants of various species, chiefly *Bromus rigidus*. Near Yreka, along an overflow ditch in which there is standing water during the winter, *P. bulbosa* var. *vivipara* and *Juncus patens* occupied the entire area and were present in approximately equal amounts and in the near vicinity, on open unirrigated hillsides, bulbous bluegrass constituted the chief vegetation. In still other locations near Montague and Yreka, the same grass, with the tops mature or entirely gone, but with the bulblets at the base forming dense mats, was found in gravelly places along roadsides and in fenced yards protected during the summer from poultry. It was also present in the same neighborhood on very heavy adobe soils.[5]

[5]Unofficial reports from farmers near Yreka indicate that *P. Bulbosa* was first observed in that section in 1905 when plants were found in several fields of alfalfa the seed for which was reported as coming from Turkestan.

The temperature conditions in these California localities are similar to those described for the region west of the Cascade Mountains.

In the matter of elevation, *P. bulbosa* is growing at about 50 feet above sea-level at the University Farm, Davis, Calif.; at altitudes of approximately 2,600 feet in the above-mentioned localities in Siskiyou County, California; and at an elevation of 4,600 feet in the Siskiyou Mountains in Oregon, approximately 20 miles north of the California-Oregon boundary. In the last mentioned locality, the bulbils were planted in snow in March, 1930, in an area densely shaded by pine trees.

Near Red Bluff, Calif., *P. bulbosa* was sown broadcast with *Vicia villosa* in the fall of 1930 on very rocky land from which the native growth of shrubs and trees had been burned during the preceding summer. Both species produced thin stands and were approximately 12 inches tall when observed on April 28, 1931, *P. bulbosa* being mature and *Vicia villosa* just coming into flower. In the same locality, on cultivated land, an extensive area of bulbous bluegrass and alfalfa was sown in 1930.

In Tuolumne County, Calif., *P. bulbosa* was sown in the fall of 1929 on heavily burned-over land and succeeded in establishing itself the first year. However, this stand was virtually a total failure in 1931.

A large number of experimental plantings made in 1928 in other parts of California have proved unsuccessful.

Specimens of *P. bulbosa* collected from each of the California and Oregon habitats and localities inspected by the junior author are in the herbarium of the Division of Agronomy, University of California. Most of the California plantings and a number of those in Oregon were inspected jointly by both writers in April, 1931.

Information from B. W. Wells, North Carolina State College of Agriculture and Engineering, indicates that *P. bulbosa* planted in Bermuda grass, *Cynodon dactylon*, failed to spread rapidly on Cecil red clay loam soil on the college campus.

Reports on various trials with *P. bulbosa* in the southeastern part of the United States beginning in 1925 have shown unfavorable results.

OBSERVATIONS IN FOREIGN COUNTRIES

Harold T. Pence, Agriculturist, Gaziantep, Turkey, states in a communication dated in March, 1931, that *P. bulbosa* is very aggressive there on limestone soils which are less than 1 foot deep, dis-

placing practically all other vegetation. In a few places, *Lolium perenne* seems to withstand the competition.

Dr. Alex McTaggart, Council for Scientific and Industrial Research, Canberra City, Australia, states in a letter that *P. bulbosa* is probably the earliest-maturing grass among the numerous introductions into Australia. He states further that tests made with this grass from bulbs or bulbils received from Oregon, California, and Virginia show it to be strikingly subject to rust.

In the herbarium of the University of California there is a specimen of *P. bulbosa* No. 322660 collected June 8, 1922, by R. R. Stewart 1742 at an elevation of approximately 10,000 feet on Mt. Mahadeo, India, and other specimens (Nos. 282885 and 282886) collected by R. C. Ching 691 and 693 in La Che Fze Mountains south of Sining Kansu at elevations up to 12,000 feet.

SUMMARY

Original observations on *P. bulbosa*, chiefly var. *vivipara*, in the United States, supplemented by data in the European literature and from a few unpublished sources, indicate a wide distribution for this grass.

It is found on a large number of soil types, including rocky, gravelly, sandy, clay, adobe, limestone, alkali, and glacial formations. It is found in semi-desert regions and in forest areas; on dry, drained lands and on overflow lands, and in snow-covered regions; in open sunlight and in dense shade; along roadsides; on infertile, virtually bare land, and in cultivated fields; and at elevations from sea-level to above 10,000 feet. This grass is distributed over wide areas of the earth's surface.

Quite often the growth and stands during the first year after planting are small and spotted. The dual multiplication method of *P. bulbosa* makes possible a fairly rapid increase of plants. Thin stands on land adapted to its growth will usually, within 3 or 4 years, thicken very materially and, if other conditions are favorable, full stands result.

From the agricultural standpoint, *P. bulbosa* is at present most widely used and of most farm value in the United States in southern Oregon and northern California, where it is becoming well established in some sections and is frequently dominant under the conditions to which it is especially adapted.

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CALCIUM AND HYDROGEN-ION CONCENTRATION IN THE GROWTH AND INOCULATION OF SOYBEANS[1]

WM. A. ALBRECHT[2]

The common failure of legumes on sour soils has led us to believe that the soil acidity, or degree of reaction, is responsible. Little attention has been given to the deficiency of calcium as the possible cause, and further consideration needs to be given the question whether legume failure is caused by the harmful effects of the excessive degree of acidity, or by the failure of the plants to obtain sufficient calcium. In mineral, humid soils, the increased deficiency of calcium usually parallels the excessive degree of acidity (6).[3] Also the use of calcium carbonate on sour soils functions both to supply calcium and to reduce the degree of acidity. Thus, the two possible causes have not

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[2]Professor of Soils. The author is indebted to Dr. Hans Jenny for most of the experimental work here reported and for his careful and critical attention to the problems involved.

[3]Reference by number is to "Literature Cited," p. 806.

been differentiated, and it is readily possible that causal significance has been ascribed to the wrong one of two contemporaneously variable factors. It seems highly essential that we separate these to learn whether legume failure can be ascribed wholly to the excessive hydrogen-ion concentration of the soil or to the deficiency of calcium and its proper functioning in the legume growth

The particular function of calcium in the plant can not be so readily determined because of the difficulty of controlling accurately the calcium in the soil, and the fact that its ionic form in a water culture may function differently than the adsorbed soil form. Recent developments in the technic of manipulating soil colloids suggested a means of controlling calcium conditions to greater refinement than possible in simple quantitative chemical methods, and a study of the importance of calcium in growth and nodule production of legumes was undertaken with the hope of understanding better the significance of the element calcium in these crops

Previous work has pointed to calcium as important in soybean inoculation (1, 2, 5), and suggested that it does not exercise this importance so much through its direct influences on the bacteria. These remained viable in an acid soil even though they failed to produce nodules. Inoculated sour soils which failed to produce nodules gave a nodulation increase of 300% when given calcium but no additional bacteria (1). That the lime functions through the plant more than through its effects on the bacteria is indicated by a significant increase of nodules on the plant grown for 10 days on a calcium-bearing sand and then transplanted to an acid, but well inoculated soil (1). This same preliminary treatment of the plants for 10 days in calcium-bearing medium also gives greater growth and greater nitrogen fixation in the plants' early history (3). These facts led to a more careful study of legume growth and inoculation by the use of electrodialyzed colloidal clay as a means of supplying calcium under conditions controlled for (a) the reaction and (b) the amount of calcium supplied.

METHODS

The electrodialyzed clay titrated with different amounts of calcium hydroxide served to give varied hydrogen-ion concentration (pH), and an inversely varied amount of calcium. The colloid of this type contains mainly adsorbed calcium and hydrogen ions and introduces no other significant disturbing factors. The selection of different degrees of calcium saturation made possible constant but different pH values, while the use of different quantities of clay per seed gave different but constant amounts of calcium. Clays so selected were

mixed with a leached silica sand and served as a medium for the growth of soybeans previously germinated in plant-food-free sand. The treated clay permitted an approximate range in pH from 3.5 to 7.0. The concentrations of clay in the sand ranged from almost insignificant amounts to quantities never large enough to disturb the good physical condition of the sand. In the early work this never exceeded 2%.

No other plant foods were added, since inoculation may take place under normal conditions of the soybean as early as 14 days, and the cotyledon probably carries a reserve of the elements necessary for this short period of growth. Ionic calcium in the form of solutions of acetate and chloride titrated with their acids was used for comparison with that adsorbed on the clay colloid. The plants were grown in different trials, first, by varying the amount of calcium and inversely the degree of acidity, second, by varying only the acidity at constant amounts of calcium, and third, by varying only the calcium at constant acidity.

EXPERIMENTAL RESULTS

In the first trials, which used the clay titrated to different degrees of saturation, the amounts of calcium were so low that difficulty occurred in obtaining growth of the plants. Their very earliest growth seemed normal but was followed by a diseased condition resembling damping-off. The number of plants with apparently normal growth varied with the treatment, becoming more numerous with increased calcium and lessened acidity. This effect was far more pronounced for the calcium as acetate than for the calcium in the colloidal clay, suggesting the more ready availability of calcium in the acetate or free form than in the adsorbed form. The growth, or weights, ran parallel with the percentage of healthy plants, as shown in Fig. 1. A trial along this same plan, supplying large amounts of calcium, produced good growth with most of the plants normal as shown in Fig. 2. The introduction of the proper bacteria failed to produce nodules. Very few of the plants grew to significant size and the study was directed to work out more fully the relation of growth and nodulation to calcium and the acidity.

Clays were prepared at different degrees of saturation, and therefore different degrees of acidity within a pH range from 3.84 to 6.94. The calcium was maintained constant as amounts per seed by using more clay of the higher acidity and less of the lower acidity. Two levels of calcium were taken, *viz.*, low calcium at 0.014 M.E.[4] per plant and high calcium, at 0.35 M. E. per plant. The results of this trial

[4]Milliequivalents.

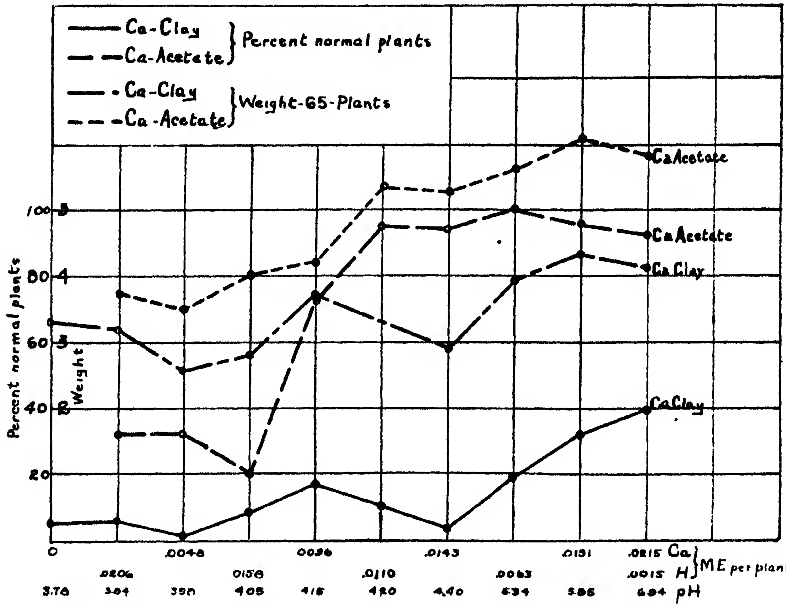

FIG. 1.—Growth of soybean plants on varying amounts of calcium and inversely varying acidity, maximum calcium 0.0215 M. E. per plant

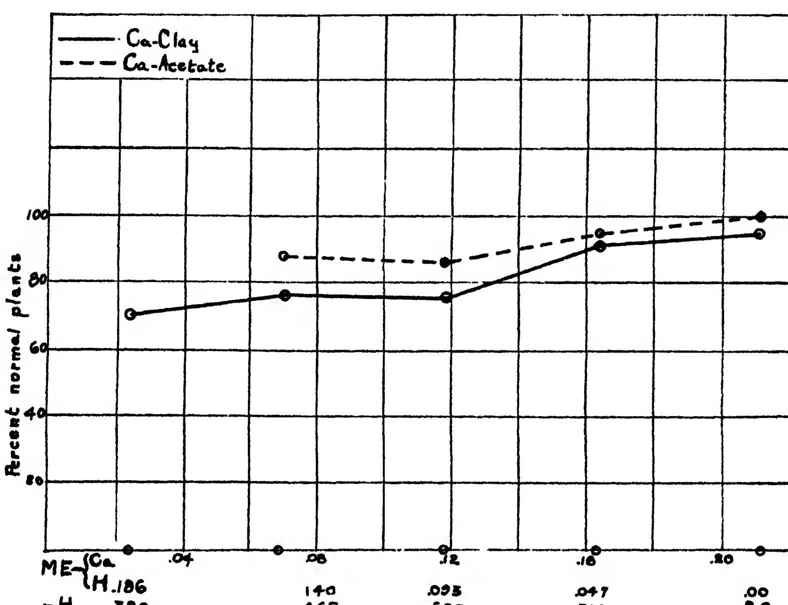

FIG. 2.—Growth of soybean plants on varying amounts of calcium and inversely varying acidity, maximum calcium 0.20 M. E. per plant.

are given in Fig. 3 and 4, and point clearly to the fact that with the low supply of calcium the growth, measured in terms of both normal plants and weights, was erratic, irrespective of pH, while with the higher supply of calcium, the growth was good regardless of the degree of acidity.

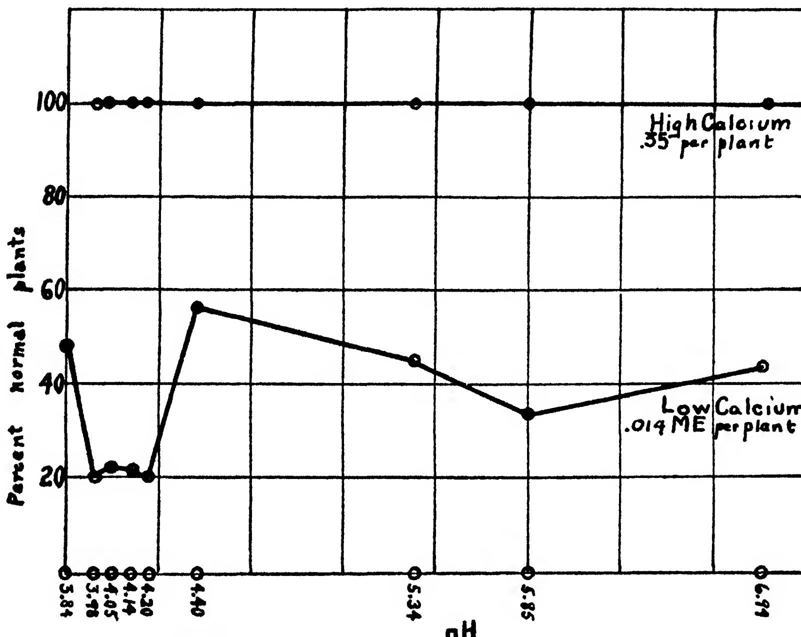

FIG. 3.—Percentage of normal of soybean plants as grown on low and high amounts of calcium per seed through a pH range from 3.84 to 6.94.

Since the previous trial points to the importance of the calcium more than to the hydrogen-ion concentration, it was necessary to determine the significance of the amount of calcium in the plant growth. Another trial was undertaken in which this was varied in one series through a range from 0 to 0.042 M. E. per seed at a pH of 6.94 (neutral) followed with a duplication at pH 6.92 through calcium from 0–0.35 M. E. per plant grown as individual plants, and another series through a variation from 0.0086 to 0.0308 M. E. at a pH of 4.4 (acid). The results in this trial as given in Fig. 5 and in Tables 1 and 2 show that the growth is associated with the amount of calcium (within the ranges used) and that growth is quite independent of the pH. The acetate serves better to supply the calcium than does the clay colloid at these low amounts of calcium. This points rather definitely to the significance of the calcium in producing the growth

and emphasizes the fact that if this element is present in either the free or adsorbed form in sufficient amount, growth seems normal irrespective of the degree of acidity.

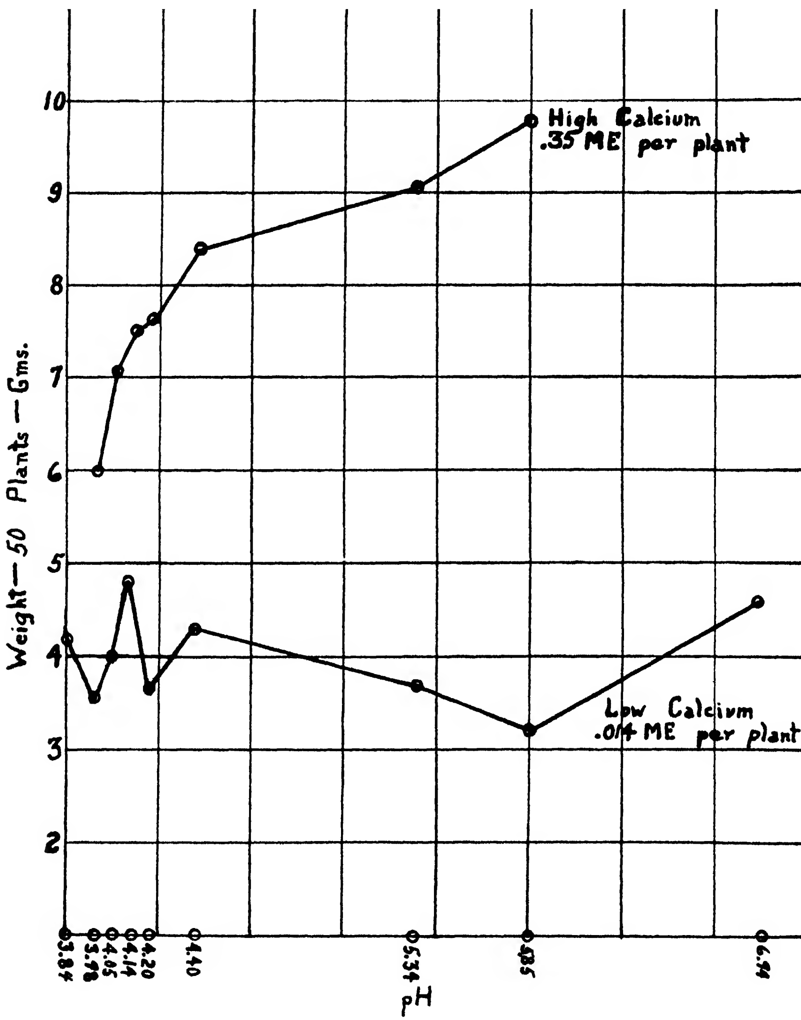

FIG. 4.—Weights of soybean plants grown on low and high amounts of calcium per seed through a pH range from 3.84 to 6.94.

Inoculation was applied in all these trials, but no significant nodule production occurred except that there was a suggestion that the nodulation will occur as larger amounts of calcium (approaching 0.30 M. E.) are available to the plant. Growth was terminated after

TABLE 1.—*Growth as related to the amount of calcium at constant pH (neutral, 6.92), summary of 200 plants grown individually.*

M. E. of calcium per plant	Normal plants %	Weight of one plant, grams	Nodules per plant
	Calcium clay		
0	0	0.0829	0
0.005 to 0.05	71	0.1244	0.04
0.06 to 0.20	93	0.1828	0.23
0.25 to 0.35	97	0.2003	0.13
	Calcium acetate		
0	0	0.0829	0
0.05 to 0.10	75	0.1554	0.5*
0.30	100	0.2571	5.6

*Only near 0.10 M. E. per plant.

TABLE 2.—*Growth as related to the amount of calcium at constant pH (acid, 4.4).*

M. E. of calcium per plant*	Normal plants %	Total weight of 65 plants, grams	Average weight of single living plant, grams
0	0	4.26	0
0.0086	60	4.39	0.0687
0.0192	92	5.67	0.0890
0.0308	100	6.37	0.0980

*Calcium clay.

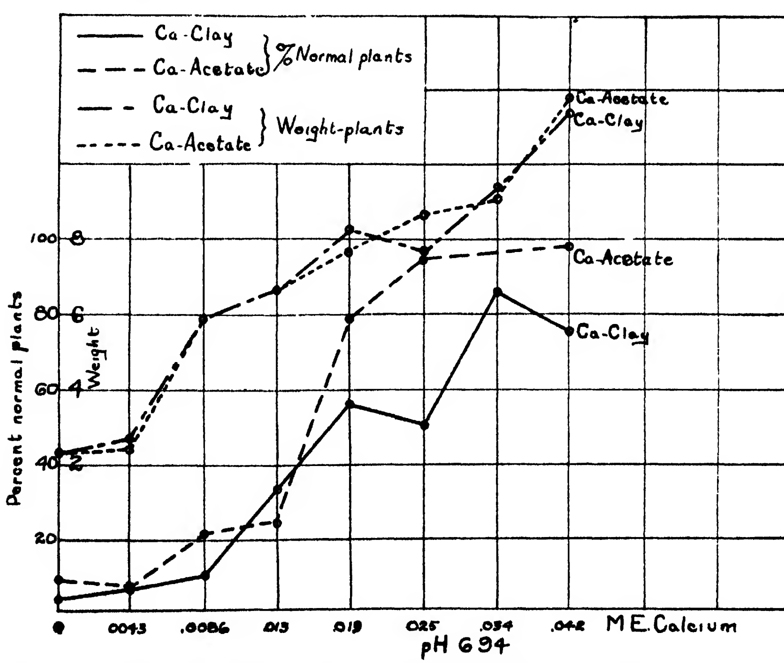

FIG. 5.—Growth of soybean plants on varying amounts of calcium per seed at pH 6.94.

relatively short intervals, though long enough to permit nodulation under normal conditions. Since growth was obtained with difficulty, it is readily possible that even this growth was an abnormal condition for nodule production.

Since growth in these trials was closely correlated with the presence of calcium and its concentration and not with the hydrogen-ion concentration, it points out clearly that calcium is far more effective in producing growth than excessive hydrogen-ion concentration is in prohibiting it.

TABLE 3.—*Nodulation of second crop of soybeans on sands given calcium carbonate as supplement to treatments of preceding crop.*

Previous treatment	Total plants	Total nodules	Infected plants, %
Potassium chloride+inoculation. .	69*	89†	76
Magnesium chloride+inoculation .	66	81	71
Calcium chloride+inoculation . .	69	111	87
Calcium acetate+inoculation	66	51	40

*Eleven pots with five to eight plants each were used in each treatment.
†The check contained three jars with 21 plants. Only two nodules were found on one plant.

In the preceding trials attention was directed only to calcium and hydrogen. There arises also the question whether other nutrient cations might not function likewise and play a rôle correspondingly as important as that of calcium. Methods of test, similar to those used previously, were employed to try the importance of potassium and magnesium as chlorides in comparison with calcium in this and the acetate forms, all at initial pH 7.00. The results are given in Figs. 6 and 7. Increasing amounts of each salt improved the growth. With potassium chloride this ranged from 6 to 26 % normal, with magnesium chloride from 4 to 88% and for calcium chloride and calcium acetate marked improvement occurred with every increment, while normal growth was obtained as soon as a certain minimum of calcium (approximately 0.023 M. E. calcium per seed) was reached.

Nodulation was observed in these trials testing calcium, magnesium, and potassium only in the higher concentrations of calcium as acetate (at 0.017 and 0.043 M. E. calcium and above). Consequently, the sands as used were given clacium carbonate (1), reseeded, but not re-inoculated. Growth was normal and nodulation developed, according to the data in Table 3. This points clearly to the greater significance of calcium in larger amounts to bring about nodulation that had previously failed.

Gedroiz (4) used oats, mustard, and buckwheat plants in soils dialyzed free of their calcium but saturated with other bases and

reports that, "Plants are thus able to utilize the elements magnesium and potassium in a soil from which the exchangeable bases of these elements were removed practically completely. When the other

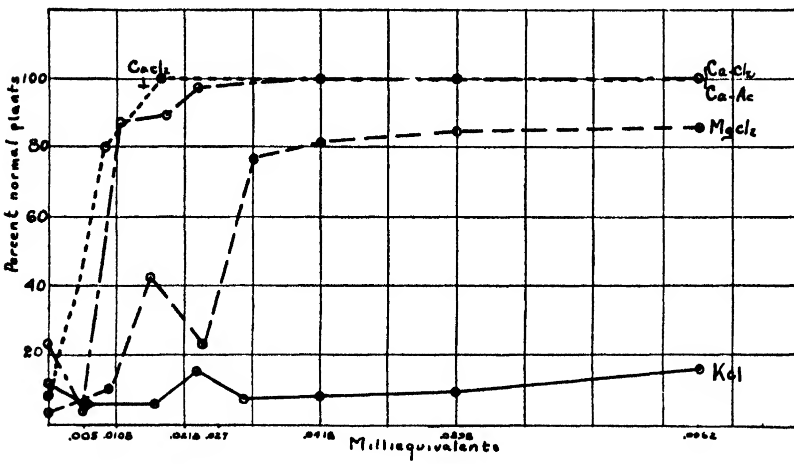

FIG. 6.—Percentage of normal of soybean plants as grown on salts of potassium, magnesium, and calcium supplying varying amounts of each, initial pH 7.00.

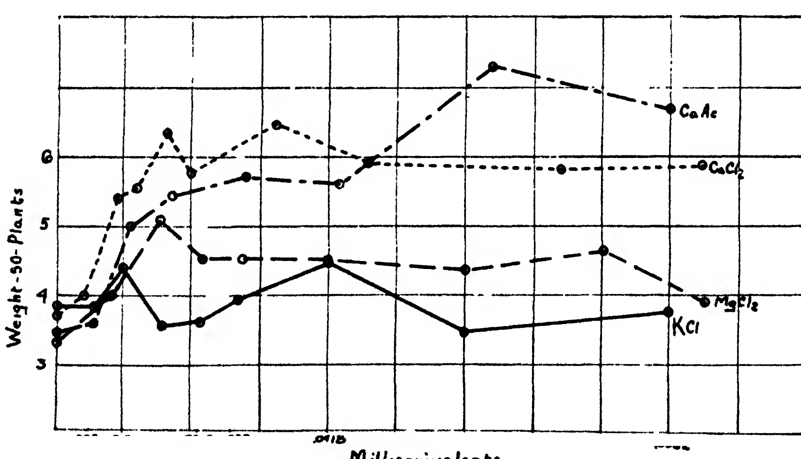

FIG. 7.—Weight of soybean plants grown on salts of potassium, magnesium, and calcium supplying varying amounts of each, initial pH 7.00.

nutritive elements were provided, high yields were obtained. Totally different results are obtained concerning the role of calcium in the plant nutrition; if practically all the exchangeable calcium is removed from the soil and is then replaced by a base, the presence of

which does not prevent the development of the plant in one way or another, then. . . . the plant dies entirely when no calcium salts are added to the soil." This points to a similar significance of calcium for non-legumes, such as oats, mustard, and buckwheat, as suggested for soybeans in the tests reported here. Gedroiz places the importance of calcium not only over magnesium and potassium, but also over the other bases sodium, aluminium, iron, hydrogen, manganese, lithium, and ammonium. This can not be with the same force in connection with strontium, which he believes "may to a certain extent take the place of calcium for plant growth." Nevertheless, of a total list of 16 bases used to saturate the soil fully, he believes that "the plant . .points to a very special position of exchangeable calcium among all the bases tested "

As for the base hydrogen, Gedroiz believes this ion injurious, contrary to the results suggested in the studies here presented. In failing to obtain crop growth on a soil fully saturated with hydrogen-ions and given no calcium carbonate, he says, "Two causes prevented their growth: the absence in such a soil of available calcium, and the acid reaction." He points to the injurious effects by the acid reaction, since his introduction of calcium sulfate in place of calcium carbonate into a hydrogen-saturated soil fails to produce a crop. Yet, in his explanation, it is suggested that the sulfuric acid formed from the introduction of calcium sulfate into a hydrogen-saturated soil may be the cause of plant growth failure, which is a detrimental factor quite different from the adsorbed hydrogen-ion of the soil, and does not necessarily prove the hydrogen-ion in acid soil as the injurious factor.

These results thus far emphasize the significance, first, of the element calcium itself; second, of the quantity of calcium present; and third, of its association with different cations (acetate, chlorine, clay). The latter point suggested a trial of calcium in different forms to include (a) the acetate, providing calcium in the free, diffusible, ionic form; (b) calcium permutit, with calcium in the adsorbed form, becoming free through exchange with other cations; and (c) anorthite, carrying calcium in the insoluble crystal form of this alumino-silicate mineral. The individual plants were grown at pH 7 with a supply of calcium varying through a range from 0.0125 to 2.50 M.E. per plant. The growth is represented in Fig. 8. The calcium acetate produced normal plants, the permutit produced such only at higher concentrations, while the anorthite failed at all concentrations. This points out clearly that the "availability" of the calcium or degree of being free is a significant factor as well as the amount of this element per plant.

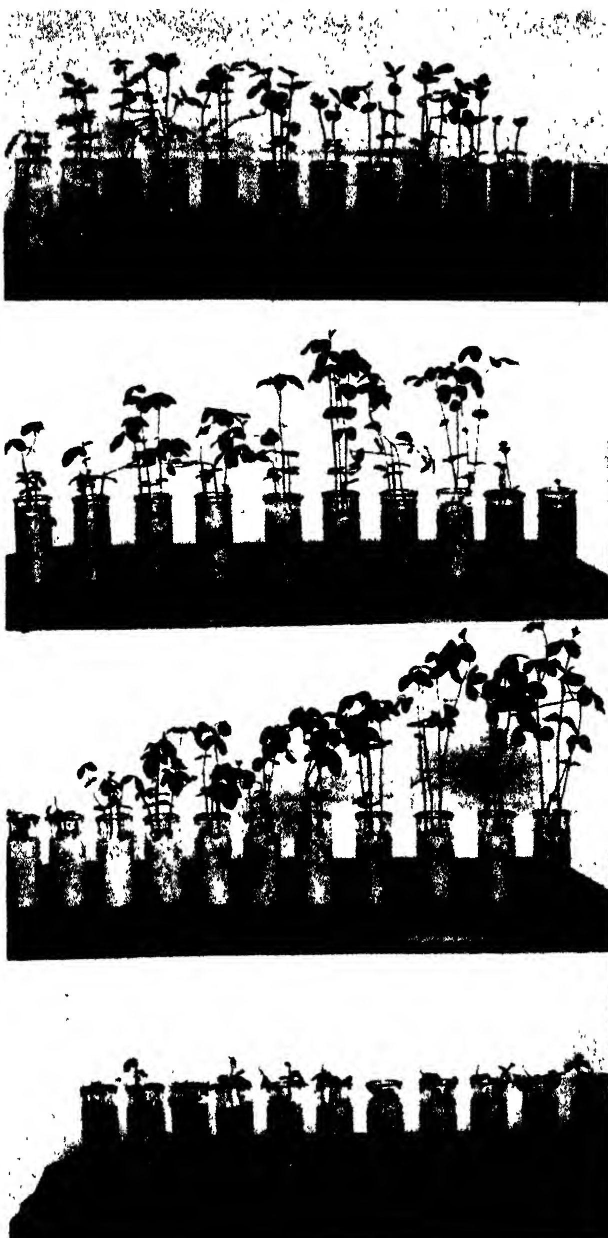

FIG. 8.—Soybean plants receiving calcium as (1) chloride, (2) acetate, (3) permutit, and (4) anorthite at initial pH 7.00, increasing amounts from left to right.

Though inoculation was applied regularly in all the preceding work, irregularity of growth was the outstanding result and nodules failed to develop in most cases, except when increasing amounts of calcium were applied. This led to other attempts to produce nodulation by still larger amounts of calcium per seed applied by means of clay. The plants were grown in the individual containers and given variable amounts of calcium at the constant pH 7.0 (neutral) and associated with different cations. Two different trials are represented. The results are given in Table 4. In these trials nodulation was obtained in few cases of the lower calcium concentration, but increased with increasing amounts of calcium. These confirm, in part, the previous trials in which nodulation failed in the lower calcium concentration but developed in the calcium acetate above 0.043 M.E., and in the calcium clay above 0.05 M.E. per plant (Table 1). At this concentration and all those above it, nodulation occurred, suggesting this as a possible lower limit for nodulation under the conditions of the experiment.

Again the amount of the calcium, its form, and the associated cation emphasize themselves. The ionic, free forms produce nodulation at a concentration lower than that of the adsorbed form. It is particularly interesting to note that the calcium carbonate was as effective, if not superior, to all other forms. At the much larger amounts of calcium used in these trials growth was always normal and nodulation very satisfactory. Further trials of these larger calcium amounts at other hydrogen-ion concentrations are needed.

SUMMARY

The data as a whole suggest that, with the minimum amounts of calcium used, the plants are readily attacked by disease and that only poor growth without nodulation occurs. With increased amounts of calcium, growth improves and seems to be normal, but only as still greater amounts of calcium are available to the plant will nodulation occur. Though only two trials of larger amounts of calcium at one hydrogen-ion concentration were used to bring about nodulation, they suggest a minimum necessary calcium for nodulation with improved nodule production as this is increased. This suggests that the calcium supply must first meet the requirements for growth and then an additional amount of this element is needed to permit the nodulation. Further, the data point out clearly that the significance of calcium for the soybean plants rests on its function as an element in the plant's activities rather than on that of reducing the hydrogen-ion concentration of the soil or growth medium.

TABLE 4.—*Nodulation of soybeans with varying amounts of calcium (pH 7.00), nodules per plant as average of eight plants.**

M. E. of calcium per plant	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	Total
First Trial											
Calcium acetate	—	0.37	0.10	2.50	2.62	2.62	0.25	3.50	4.37	4.25	20
Calcium carbonate	0.75	0.62	2.75	3.25	3.50	4.62	6.25	5.50	3.37	4.50	35
Second Trial											
Calcium chloride	—	2.13	3.00	3.00	4.37	2.50	2.75	5.62	6.00	5.50	33
Calcium permutit	—	—	—	1.13	—	2.13	—	1.87	—	3.50	9
Calcium acetate	—	—	1.50	2.25	1.87	2.50	2.37	2.00	2.13	2.00	16
Calcium clay	—	—	0.37	2.00	4.13	3.62	4.50	3.00	4.13	4.13	26
Calcium bentonite	—	—	—	1.00	2.13	2.37	3.13	4.75	2.87	3.62	20

*Data by Eugene W. Cowan.

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THE PRESENCE AND DISTRIBUTION OF SULFOFYING BACTERIA IN MINERAL AND PEAT SOILS[1]

J. K. WILSON AND H. W. HIGBEE[2]

The soil bacteria population may be divided into two classes, the separation being made upon the biochemical processes performed by each. The autotrophic bacteria, in contrast to the heterotrophic, are those that derive part or all of their energy requirements from the oxidation of inorganic substances. Those that oxidize inorganic sulfur and its compounds may be classified for convenience in three groups. One group in particular is active in the oxidation of sulfur in field soil. It is represented by several types, but at present their physiological characters have not been studied sufficiently so that one can easily differentiate between them.

During the mineralization of organic materials, such as crop residues and organic fertilizers by heterotrophic bacteria, the sulfur contained in them is changed from a high potential substance to one of lower potential, the energy liberated being at the disposal of the organisms. Free sulfur may be produced in the process. It is logical, therefore, that as the supply of sulfur from sulfur-containing material fluctuates, the number of autotrophic sulfur-oxidizing bacteria may also vary. This is probably true for all sulfofying organisms whether they use sulfides, elemental sulfur, or any intermediate compound between sulfur and sulfate.

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication March 5, 1932.

[2]Professor and Assistant in Soil Bacteriology, respectively.

The soil complex in addition to the sulfur supply may be a dominant factor in controlling the development and continued existence of sulfofying organisms. For satisfactory growth of the two groups that are not considered in this paper, excess basic material, as well as proper sulfur compounds, must be provided. Certains members of the other group, representatives of which are found in agricultural soil, can oxidize elemental sulfur and inorganic sulfur compounds only very slowly at pH 7.5, while at pH 5.9 growth occurs quite freely and at pH 4.8 growth is exceedingly rapid, being accompanied by a large increase in sulfate.

Much arable land, whether organic or inorganic, even if not apparently deficient in bases, is more acid than pH 6.5. Such a soil complex together with a scarcity of the proper sulfur compounds, limits the type and numbers of sulfur oxidizing bacteria to those that can tolerate an acid condition and perhaps a meager supply of sulfur or to those that can obtain energy also from other sources. Since the final product of sulfur oxidation is one that is readily assimilated by many organisms, i.e., sulfate, the importance of such a process in arable land is very evident. The relation sulfofication bears to the production and maintenance of acid condition in the soil complex and to the production of plant nutrients has led to a study of the presence and distribution of bacteria capable of oxidizing elemental sulfur.

Information concerning other autotrophic bacteria, such as the nitrifying organisms, may lead one to believe that wherever sulfur is being liberated, whether from sulfur mines, from organic matter, or from sulfate compounds, a sulfur-oxidizing flora may be found. However, this may not always be true, at least of all species.

Skinner and Nygard (6)[3] examined 55 peat soils for the presence of bacteria that could oxidize elemental sulfur. They inoculated a sterile liquid medium containing elemental sulfur with 1 gram of peat soil and looked for a change in turbidity or in reaction of the medium during an incubation period of 60 days. Only one peat soil gave evidence of the presence of a sulfur-oxidizing organism and this soil had previously received an application of flowers of sulfur.

Jensen (4) isolated an organism from especially collected soils. These were from either near a sulfur mine or from tillable land that had been fertilized with sulfur. The organism increased the acidity of the sulfur-containing medium in which it was grown about 2 pH units and produced sulfate readily.

Drewes (3) studied the flora of a moor soil the pH of which varied from 3.5 to 4.8. He thought that this high acidity might have been

[3]Reference by number is to "Literature Cited," p. 821.

produced by biological processes. He added 10% flowers of sulfur to samples of the moor soil and incubated the mixture for 10 days. It is not stated that the sulfur was sterilized. During this time the acidity of the compost increased more than 1 pH unit. An organism from this compost was grown on a solid medium to which had been added $Na_2S_2O_3$. It resembled the one described by Waksman and Joffe (9) who obtained it originally from a compost of soil, sulfur, and rock phosphate and is also similar to that isolated by Jensen.

It is interesting to note that the above investigators, following approximately the same methods, found in the same type of sulfur-oxidizing bacterium and found it only in soils that had been fertilized with flowers of sulfur or in soils that had been exposed to sulfur contamination. This may indicate that either the native sulfur-oxidizing flora of arable soils is not very abundant or that the methods used were highly favorable to this one type of bacterium which may have been introduced along with the sulfur.

Waksman (8) states that this type of sulfur-oxidizing organism (*Thiobacillus thiooxidans*) is usually not originally present in the soil, but is introduced there artificially with the sulfur added; also that certain soils may harbor organisms that are able to oxidize small amounts of sulfur to a much smaller extent than *T. thiooxidans*

Skinner and Nygard (6) state that no one has isolated this organism from American soils that have not been fertilized with elemental sulfur. It is very evident that elemental sulfur does not accumulate as a result of the mineralization of sulfur-containing compounds, therefore, the native sulfur-oxidizing flora is perhaps responsible for the non-accumulation of this element in arable soils.

An organism that produced sulfate from flowers of sulfur was isolated by Brown (1) from field soil that had received no elemental sulfur. It resembled in many ways the organism described by Waksman and Joffe (9), but in others it appeared entirely different. Since it was a member of the native sulfofying flora, it seemed advisable in the present study to follow fairly closely the method used by Brown in his work. His method was quite similar to that used by other investigators, the principal difference being the character of the nutrient solution employed. With slight modifications this solution has been used by us in the present study. A detailed description of its preparation, together with other methods, is given below.

METHODS

In 1886, Adametz employed the microscope to study the micro-organic population of the soil. He soon recognized that this direct

method could not satisfactorily differentiate between the numerous groups that were present. In a recent article this has been emphasized again by Dianowa and Woroschilowa (2). From time to time, however, other methods were proposed for the bacteriological examination of soils. Each was designed to give information of a definite character. The method employed by Brown (1) to isolate a sulfur-oxidizing organism was made highly selective by the addition of elemental sulfur to the medium as a source of energy. A similar medium was employed in the present investigation and had the following composition:

$(NH_4)_2SO_4$	2 grams
K_2HPO_4	1 gram
$MgSO_4$	0.5 gram
KCl	0.5 gram
$FeSO_4$	0.01 gram
S	10–15 grams
$Ca_3(PO_4)_2$	0.03–0.04 gram
Distilled water	1 liter

To prepare this medium the salts were added to distilled water, excess tricalcium phosphate being used. After a thorough mixing the excess phosphate was allowed to settle and the solution decanted. It was then adjusted with dilute sulfuric acid, usually to pH 5.5, and 30 to 40 ml distributed either into 200-ml erlenmeyer flasks or into 4-ounce bottles. To each container was added about 0.3 gram flowers of sulfur. The containers were plugged with cotton and heated in the autoclave for about 15 minutes at 5 to 6 pounds pressure. Heating usually shifted the reaction of the medium toward neutrality about 0.4 of 1 pH unit.

In making dilutions of a soil suspension, it is possible to arrive at a point where a definite part of a gram may no longer contain a sulfur-oxidizing organism. Therefore, if a series of dilutions of a properly prepared soil sample were added to the above sterile medium which seems to be suitable for the growth of certain sulfur-oxidizing bacteria their by-products should accumulate and it should be possible to decide whether the organism was present or absent. In this case the by-product probably was an acid, therefore an increase in acid reaction of more than 0.4 of a pH unit was usually taken to indicate the presence of the organism. In doubtful cases sub-cultures were made and the reaction of the sub-cultures determined after a suitable incubation period. It was assumed that any organism that could oxidize the sulfur in this medium and create an acid condition belonged to the sulfofying flora of the soil. Microscopic examinations of numerous dilutions, sub-cultures, and agar slope growths were made

from time to time in order to observe the characteristics and variability of organisms present. This method of procedure was developed and successfully used by Hiltner and Störmer.

Suspecting that the numerical presence of sulfur-oxidizing bacteria may be controlled largely by the supply of available sulfur, it was difficult to estimate the exact quantities of soil that should be taken in order to establish a series of increasing dilution that would indicate where the sulfur-oxidizing bacterium was present and where it was absent. As a result, at first, a rather wide range of dilutions representing definite quantities of soil was used. As information was obtained concerning the numerical presence of these organisms in a soil it was possible to use a narrower range and a smaller number of dilutions and to determine more accurately by this indirect method the number of such organisms.

In a series of dilutions that were used to establish the approximate number of sulfur-oxidizing bacteria, especially where considerable quantities of soil were used, such as 2, 1, 1/10, 1/50, 1/100, 1/250, 1/500, 1/1,000th gram, it was frequently noticed that the dilution representing the largest quantity of soil was not always the first to show an increase in acidity. Very often it would be the dilution representing 1/50th gram or even 1/100th gram. This is believed to be due to the buffering effect of the added soil. On subsequent incubation the dilutions containing larger quantities of soil would begin to show an increase in acidity.

It is doubtful whether every gram of soil in a field plat contains the same number of sulfur-oxidizing bacteria. Therefore, an effort was made to obtain a sample that would be fairly representative. When field or plat samples were taken they consisted of many borings. These were used to make a composite. From this enough was taken to give 100 grams of dry soil. When peat samples were analyzed they were taken either from a sample previously air dried and ground to 100-mesh fineness, 10 grams being used, or from very large composite samples in which case the equivalent of 50 grams of dry material was used. In case of soil culture studies the entire culture was analyzed. This also represented 50 grams of solid material. If quantities as large or larger than 1 gram of dry material were needed to establish the presence of the bacteria, they were weighed from the composite sample. All other samples were thoroughly dispersed in sterile water, either by shaking or by a mechanical agitator from which suitable quantities were used. Nitrates were determined by the phenoldisulfonic acid method. The reaction of the collected soil samples and of all culture solutions was determined either by the quinhydrone method or by the colorimetric method, or by both.

RESULTS OF DETERMINATIONS

In this study of the number and distribution of sulfofying bacteria in soils it was desirable to obtain samples for analysis of several representative soil series of New York State. Those that were obtained represented mineral and peat soils. In some cases the determinations were made on the fresh sample, while in others they were made on air-dried samples, some of which had been stored for 7 years.

NUMBER OF SULFOFYING BACTERIA IN MINERAL SOIL

Two samples from each of three soil types appeared suitable for preliminary work on this subject. The soils from which they came had been used in a fertilizer test of soil types. A brief description and history of these soils is given here. A more detailed description is given in Bulletin 520 of Cornell University Agricultural Experiment Station. These soil types were taken from quite widely separated locations, brought to the Experiment Station and placed in galvanized iron rims imbedded in the ground to a depth of 3 feet. These soils had been in these rims at least 10 years before the present determinations were made. They were cropped during this period and received complete fertilizer each year. The fertilizers were nitrate of soda, superphosphate, and potassium chloride. It is evident from the data presented in Table 1 that applications of ground limestone increased the pH readings of the soils. Only the two soils of the Ontario series were naturally alkaline.

These soils had been in a rotation of barley, red clover, fodder corn, and timothy. It was in May, 1928, following the timothy crop of the previous year that samples were taken for a determination of the number of sulfofying bacteria. The samples were brought to the laboratory and handled as outlined above. They contained from 17 to 20% moisture. The soil series, together with the treatments they received, their reaction, and the approximate number of sulfur-oxidizing bacteria are given in Table 1.

Thirty determinations were made. Table 1 shows that these represented two fertilized and limed, two limed, and one natural soil of each soil type. There were two samples each of three soils types. These soil types had comparatively few sulfur-oxidizing bacteria per gram. This was true irrespective of fertilizer and lime treatment or of lime treatment alone. Two determinations showed 50 per gram, while 9 showed 10 per gram, 3 showed 3 per gram, 3 showed 2 per gram, and 13 showed 1 per gram. During the incubation period, which was 28 days, many dilutions where the sulfur bacteria were

TABLE 1.—*Number of sulfur-oxidizing bacteria in three soil types, May 14, 1928, moisture of samples 17 to 20%.*

Cylinder No.	Soil series and county	Treatment	pH of soil	Approximate number of sulfur oxidizers per gram
29	Dutchess silt loam from Orange	FL*	7.8	10
30		L	8.0	50
31		None	5.1	10
34		FL	7.5	10
35		L	7.5	10
36	Dutchess silt loam from Dutchess	FL	8.0	50
37		L	8.0	1
38		None	5.8	1
41		FL	8.0	10
42		L	8.1	10
43	Volusia silt loam from Cayuta, Tompkins	FL	7.9	1
44		L	7.9	1
45		None	6.0	1
48		FL	7.6	1
49		L	8.0	1
50	Volusia silt loam from Turkey Hill, Tompkins	FL	7.9	1
51		L	7.8	1
52		None	5.4	1
55		FL	7.8	1
56		L	7.9	1
71	Ontario loam from Oneida	FL	8.0	3
72		L	8.0	3
73		None	7.0	3
76		FL	7.9	10
77		L	8.0	10
78	Ontario loam from Monroe	FL	7.8	2
79		L	7.8	10
80		None	7.7	2
83		FL	7.8	2
84		L	7.8	1

*FL = Complete fertilizer and lime; L = Lime only.

present developed a reaction of pH 3.8, although the original culture solution was pH 6.4 and the most acid soil used as the inoculum was pH 5.1. It was impossible to conclude from these data whether a fertilizer composed of nitrate of soda, superphosphate, and potassium chloride combined with lime or lime alone either increased or decreased the number of sulfofying bacteria over that which the normal soil contained. If the differences in numbers per gram shown in the table are broad enough to permit comparisons, the soil types stand in the following order: Dutchess silt loam, Ontario loam, and Volusia silt loam.

SULFOFYING BACTERIA IN CERTAIN SOIL TYPES IN SPRING AND IN FALL

Certain other samples were collected for analysis. Some of these were from soil types located near Ithaca, N. Y., in Tompkins County. Collections were made in the spring and again in the fall from areas that probably had never been fertilized. The remaining part of the sample that was collected in the spring after determinations were made of the number of sulfofying organisms was air dried after 36 days, kept in jars afterwards, and examined again 4 months later. This was done in order to determine the effect of drying on the sulfofying flora. A soil type at Geneva, N. Y., was also sampled. This was chosen because certain plats had received definite treatments for 31 years and were provided with adjoining no-treatment plats for comparison. Collections were made from these plats also in the spring and in the fall. Data given in Table 2 show the results of the determinations of the number of sulfofying organisms in all these samples.

TABLE 2.—*Number of sulfofying bacteria in certain soil types in spring and in fall, 1920, incubation period at least 30 days.*

Soil type	Number of bacteria per gram		Number bacteria per gram in sample collected in spring, dried, and held 5 months
	Spring	Fall	
Volusia stony loam	100	200	125
Wooster gravelly silt loam	125	200	80
Canfield silt loam I	100	1,000	60
Canfield silt loam II	75	6,000	60
Canfield silt loam III	100	1,000	80
Lansing silt loam I	750	10,000	80
Lansing silt loam II	1,000	10,000	100
Lansing silt loam III. .	750	10,000	100
Lansing silt loam IV	125	4,000	60
Lordstown silt loam	1,000	10,000	150

Dunkirk

Plat No.	Annual treatment per acre for 31 years	Number bacteria per gram	
		Spring	Fall
2	1,000 lbs. Na_2SO_4*	1,500	10,000
3	Nothing	2,000	4,000
4	2,000 lbs. $MgSO_4$	2,000	6,000
5	Nothing	750	4,000
6	2,000 lbs. $CaSO_4$	1,500	6,000
8	1,200 lbs. $FeSO_4$	1,000	6,000
9	Nothing	500	4,000
10	500 lbs. NaCl*	2,000	10,000
11	Nothing	250	2,000
12	2,000 lbs. $CaCO_3$	250	1,000

*Last 5 years application of Na_2SO_4 at rate of 1,600 lbs. and of NaCl 600 lbs.

These data show a larger number of sulfofying organisms to be present in each soil type than was found in certain other soil types, as shown in Table 1. It is rather outstanding, however, that samples taken in the spring do not show more than a few hundred to a few thousand per gram. If these numbers are contrasted with those found in samples of the same soils that were collected from the same places in the fall, it will be noted that there was a striking increase in many cases. This may be explained in a number of ways. It may be due to a higher temperature, to a larger supply of available sulfur, to a completion of other biological processes that may interfere with the sulfofication process, or to a combination of these and other factors.

It should be noted that the Dunkirk soil that received either sodium sulfate or sodium chloride had a larger number of sulfofying organisms than the no-treatment plats or than those that had received the sulfate of magnesium, calcium, or iron or calcium carbonate. It is not certain that the sodium is responsible for this increase for more than these two observations are needed before a definite statement can be made.

The effect of drying on the number of sulfofying bacteria in 10 samples is also shown. These samples represent five soil types, one soil type being represented three times and another four times. They were held 5 months in the air-dry condition. From the data it is evident that air-drying reduced the number of such organisms but did not produce sterility. The figures show one soil to have 25 more organisms in the dry sample. This may be due either to the method used in making such determinations or to an increase in numbers before the soil became too dry for growth The actual reduction ranges from a very low figure to 90% of those which were originally present.

SULFOFYING BACTERIA IN DRIED SAMPLES OF THE PRINCIPAL SOIL SERIES IN NEW YORK STATE

Since data presented in Table 2 show that drying soils and storing them for 5 months did not destroy all the sulfofying bacteria, it was thought advisable to examine air-dried samples of the principal soil series of New York State. Such samples were at hand, having been collected for the purpose of making a study of the chemical composition of New York soils.[4] The samples were taken from representative areas by means of the soil auger. A sufficient number of borings to a uniform depth of 8 inches were made to provide about 5 pounds of material. When these were received at the laboratory they were

[4]See footnote to Table 3.

spread out and allowed to air-dry. It was upon the well-mixed dry material that the number of sulfofying bacteria was determined. The samples represent 34 soil types, certain types being represented several times. A total of 76 samples was examined. The data given in Table 3 show the results.

TABLE 3.—*Number of sulfur-oxidizing bacteria in soil series and types, samples collected between 1921 and 1927, determinations made in 1929 on air-dry material.**

Series and type	Laboratory No.	Number of sulfur-oxidizing bacteria per gram
Adams fine sand	91	30†
Bridgehamton silt loam	99	100
Canfield silt loam	37, 38, 44	50, 20, 50
Chenango gravelly silt loam	95, 97	100, 100
Chenango gravelly loam	96	5
Coloma fine sandy loam	74, 75, 89	20, 5, 50
Dover loam	29, 80	40, 0.5
Dunkirk silt loam	10	0.5
Dunkirk silty clay loam	11, 72, 93	1, 10, 10
Dutchess silt loam	32, 70, 71	100, 1, 50
Gloucester loam	28, 77, 84, 90	100, 1, 20, 5
Honeoye loam	22	75
Honeoye silt loam	6, 78	5, 5
Lackawanna silt loam	33, 94	30, 50
Lansing silt loam	40, 41, 42, 43	20, 150, 40, 10
Lordstown stony silt loam	8, 31, 45, 51	5, 100, 10, 10
Merrimac sandy loam	85, 92	30, 5
Merrimac fine sandy loam	82	20
Merrimac silt loam	100	5
Merrimac gravelly loam	83	30
Ontario loam	27, 48, 52, 56, 57, 58, 79, 86	500, 20, 10, 1, none in 2 gr., 10, 5, 50
Plymouth sand	103	10
Plymouth loam	105	0.5
Plymouth loamy sand	98	75
Sassafras sand	101	None in 2 gr.
Sassafras loam	102, 104	None in 2 gr., 10
Vergennes clay loam	81, 87, 88	0.5, 50, 20
Vergennes clay	64, 69	1, 30
Volusia silt loam	5, 7, 19, 30, 49, 50	1, 1, 0.5, 75, 1, 5
Volusia stony silt loam	3, 35, 54	1, 1500, 10
Volusia silty clay loam	21	1000
Wooster silt loam	47, 53	30, 30
Wooster gravelly silt loam	4, 55	0, 5, none in 2 gr.
Worth loam	63	0.5

*For importance of series, locations where samples except 91 and 99 were taken, and chemical composition see Cornell Univ. Agr. Exp. Sta. Bul. 513.

†The laboratory numbers of the series and type and the number of sulfofying bacteria per gram are given in sequence.

Although the number of sulfofying bacteria in air-dry samples may not represent the actual numerical relationships that existed where the samples were taken, they may be valuable and do indicate a wide distribution of these organisms. The soil of every series con-

tained sulfofying bacteria. However, one Ontario loam, one Sassafras sand, one Sassafras loam, and one Wooster gravelly silt loam did not have such bacteria in the 2-gram quantities that were examined. In several other types 2 grams of soil were needed in order to find one sulfofying bacterium. The largest number found in any one of the 76 samples was 1,500. This sample was collected 7 years previously. One sample had 1,000 per gram, one 500, one 150, six 100, one 75, seven 50, two 40, six 30, seven 20, nine 10, eleven 5, and nine 1 per gram. No relationship was evident between the number of such organisms and the quantity of sulfur in the soil samples or the soil texture.

DISTRIBUTION OF SULFOFYING BACTERIA IN PEAT SOILS

It is evident from data already presented in this paper that samples from every important mineral soil series in New York State were supplied with a native sulfofying flora. It would seem, therefore, since peat soils usually contain a large sulfur supply that they too may contain native sulfur-oxidizing organisms. As a preliminary test for the presence and abundance of these bacteria in peat soil, samples of peat from cultivated areas were obtained These were gotten in late spring. Because of their high moisture content they were spread out on paper to dry so that each sample could be worked. After a thorough mixing, moisture was determined. Enough sample was taken to give 50 grams of dry material Such portions were placed in tumblers and the moisture content adjusted to that which seemed optimum for each sample. These were incubated at 23 to 25°C. During this period the moisture content was kept fairly constant by bringing the sample to its original weight. At the beginning of the incubation period nitrates and the number of ammonia and sulfur-oxidizing organisms were determined. This was repeated after 7, 14, 21 and 28 days. The readings, together with other information, are given in Table 4.

The first point to be noted in Table 4 is the large increase in nitrate nitrogen during the first half of the incubation period. While each sample clearly indicates that it is distinctly different from every other sample, yet the results tend to go in the same direction, except possibly those from samples Nos. 1 and 4. Within 14 days the accumulation of nitrates had probably reached the maximum and they remained near this throughout the experiment. It is distinctly worth noting also that the number of amonia-oxidizing organisms increased to their highest numbers in those cultures that gave the highest accumulation of nitrates, and that as soon as the nitrates reached the highest point the number of ammonia oxidizers rapidly decreased. This probably indicates that the ammonia was exhausted.

TABLE 4.—*Variation in numbers of sulfofying bacteria in incubated peat soils.*

Sample No.	pH of sample	H_2O in peat, %	Start: Nitrates	Start: Ammonia oxidizers	Start: Sulfur oxidizers	7 days: Nitrates	7 days: Ammonia oxidizers	7 days: Sulfur oxidizers	14 days: Nitrates	14 days: Ammonia oxidizers	14 days: Sulfur oxidizers	21 days: Nitrates	21 days: Ammonia oxidizers	21 days: Sulfur oxidizers	28 days: Nitrates	28 days: Ammonia oxidizers	28 days: Sulfur oxidizers
1	3.6	300	37	100	1	34	1,000	3	30	1,000	20	34	10*	2	28	10*	100†
2	5.5	250	116	1,000	20	256	1,000	10	256	1,000*	100†	160	10*	100	160	10*	100†
3	4.6	170	32	100*	2	34	1,000*	10	152	1,000*	10†	133	10*	10	128	10*	100†
4	4.4	200	43	100	2	30	1,000*	10	24	1,000*	100†	21	10*	10	80	10*	100†
5	6.0	200	150	100	3	80	5,000	100	424	25,000	100†	23	25	100†	113	10*	100†
6	6.5	170	104	500	2	320	10,000	100	1,024	50,000	100†	1,024	25	100†	1,600	10*	100†
7	5.4	170	500	500	2	840	5,000	10	3,200	50,000	100†	1,344	10	100†	1,920	10*	100†

*Less than number indicated.

†More than number indicated.

Nelson (5) showed that nitrobacter died rapidly as soon as the nitrites had been completely oxidized. Samples Nos. 6 and 7 show this very strikingly. At the start of the incubation period sample No. 6 had 500 ammonia oxidizers per gram. By the seventh day the number had increased to 10,000 and by the fourteenth day to 50,000 per gram, but by the twenty-first day it had dropped to 25 and to less than 10 per gram by the twenty-eighth day.

The number of sulfur-oxidizing organisms in all samples was quite low at the beginning of the incubation period. One sample had 20 per gram; the others had 3 or less per gram. These organisms did not increase very markedly while nitrates were accumulating. They began to increase about the fourteenth day, or as soon as nitrification ceased, and by the twenty-eighth day they had increased to more than 100 per gram in all samples. Sample No. 2 shows that nitrates had reached their highest point in 7 days with no increase in sulfur-oxidizing bacteria, but between the seventh and fourteenth day the latter had increased 10 times, while the nitrates remained the same. These data may be taken to indicate that the sulfofication process was delayed until the nitrification process had run its course.

SULFUR-OXIDIZING BACTERIA IN VIRGIN PEAT SOILS

It is evident from data presented in Table 4 that cultivated peat soils under certain conditions may contain a fair number of sulfofying bacteria. It was thought advisable, therefore, to examine virgin peat soils of New York State for these bacteria. Samples had been collected previously for a study of their chemical and physical characters. These furnished good material for a numerical study of the sulfofying organisms which virgin peats contained. All but one sample came from five more or less distinct geographical areas and for convenience these may be designated as the Orleans-Genesee area, the Wayne area, the Oswego area, the Madison-Oneida area, and the Orange area. One sample came from Livingston County. Fifty-three samples were collected in the summer and fall of 1929. They represented the first 12 inches of material. After being air-dried they were ground and stored in 2-quart mason jars. In December 1931, these samples were examined for the number of sulfur-oxidizing bacteria that they contained. Such data as seem appropriate are given in Table 5.

The figures indicate that native sulfofying bacteria were present in every sample tested despite the fact that these peat soils were air-dried more than 2 years before they were examined. While they may not be considered very abundant, they indicate the wide distribution

of this group of organisms. Like the mineral soils and the peat soils from cultivated areas (Table 4) these peats vary in their ability to support sulfofying bacteria.

TABLE 5.—*Number of sulfofying bacteria in virgin peat soils, air-dry samples collected summer, 1929, examined December, 1931, incubation period about 46 days.*

Area	Sample No.	pH of sample	Number of sulfofying bacteria per gram
Orleans-Genesee	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	6.3, 5.8, 6.0, 6.3, 5.5, 5.5, 4.6, 5.3, 5.8, 5.7, 5.8, 5.4, 5.7	100, 250, 0.5, 500, 250, 50, 10, 10, 50, 10, 100, 500, 100
Wayne	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 53	6.4, 6.3, 4.4, 3.9, 5.9, 6.5, 6.4, 6.2, 6.3, 6.5, 6.3, 6.9, 6.5, 5.5	50, 100, 0.5, 50, 500, 1, 50, 10, 50, 500, 50, 1 1, 10
Oswego	28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39	5.9, 5.5, 5.7, 5.9, 5.8, 4.6, 3.6, 5.7, 6.3, 5.5, 5.4, 3.8	0.5, 10, 0.5, 1, 50, 0.5, 10, 50, 10, 1, 10, 0.5
Orange	40, 41, 42, 43, 44, 45, 46	5.9, 6.8, 5.8, 7.6, 6.4, 5.6, 4.5	250, 50, 10, 1, 100, 100 10
Madison-Oneida	47, 48, 49, 50, 51, 52	5.7, 5.7, 5.8, 5.7, 5.6, 5.0	0.5, 50, 10, 1, 10, 100
Livingston	3	6.1	50

An effort was made to correlate the number of sulfofying bacteria with the chemical composition of the peat. No striking relationship was found between the number of such organisms and the reaction of the peat or between the number of such organisms and the content of calcium, magnesium, phosphorus, sulfur, nitrogen, and total carbon or between the number of such organisms and the ratios of these elements one to another. It should be noted, however, for the 14 samples that had approximately 1 sulfofying bacteria per gram that the average percentage of CaO was 4.83, for the 12 that had approximately 50 per gram it was 5.62, and for the 7 that had 250 and 500 per gram it was 6.56. Also, the average pH of the 14 peat samples that had about 1 such organism per gram was 5.8 and that of the 7 which had 250 and 500 per gram was 5.9. The average pH of the 12 samples that had about 50 per gram showed them to be more acid than either of the two averages given above, being pH 5.40. The reaction of the peats that had 1 sulfofying bacteria per gram varied 3.8 pH units, while that of the 7 peats that had 250 and 500 per gram varied 1.1 pH units.

DISCUSSION

The findings presented in this paper indicate that every soil series supports a native sulfofying flora. This is true of mineral and peat soils alike. Air drying did not permanently injure this flora, although it nearly always reduced the numbers of such organisms. Certain air-dry field samples that had been in the laboratory for 7 years contained very active sulfofying organisms. Also, a stock culture of a native sulfofying organism isolated by Brown (1) and used to test the methods employed in this work which was carried in soil cultures that had spontaneously dried and had remained in the laboratory for 7 years contained viable sulfur-oxidizing bacteria.

These results are somewhat different from those presented by Starkey (7) who studied the response of *Thiobacillus thiooxidans* to desiccation. He found that this organism, which was isolated by Waksman and Joffe (9) from a compost of soil, sulfur, and rock phosphate, was dead in both dried sulfur and soil in 3 days, from which he concluded that a comparatively dry environment is fatal in even a short period.

Also, these results are not in complete agreement with those reported by Skinner and Nygard (6). These workers, using approximately the same methods as were used in this investigation, examined 55 peat soils for sulfofying bacteria. They found *Thiobacillus thiooxidans* present only in one soil that had been fertilized with flowers of sulfur. They concluded that this organism has never been isolated from American soils that have not been fertilized with sulfur. The presence of other sulfur-oxidizing organisms was not observed in any sample. It would seem, therefore that *Thiobacillus thiooxidans* is not a member of the native sulfofying flora. Since it does not withstand desiccation and has been found only where sulfur has been applied, its importance in agriculture may be questioned, especially since the native soil flora can produce similar reactions.

SUMMARY

More than 200 samples were examined for the numerical presence of sulfofying bacteria. Some were freshly collected samples, while others had been in an air-dry condition for 7 years. They represented mineral and peat soils. Some were collected at two seasons of the year from the same location.

The largest number of sulfofying bacteria found in any sample was 10,000 per gram. In only four samples were the bacteria absent in a 2-gram quantity. These had been in an air-dry condition for several years.

No relationship was evident between the number of sulfofying bacteria and the reaction of the soil or between the number of such organisms and the content of calcium, magnesium, sulfur, nitrogen, or phosphorus or between the numbers present and the ratios of these elements one to another. It is indicated that an air-dry peat soil whose CaO content is high may contain more sulfofying bacteria than one whose CaO is lower.

Air-drying soils reduced the number of sulfofying bacteria but did not destroy all of them.

Data from six soil types representing 20 samples taken both in the spring and in the fall from the same location show a larger number of sulfofying bacteria in every case in those samples collected in the fall.

No one soil series was strikingly more efficient in supporting the sulfofying bacteria than was any other.

Each soil series examined, whether inorganic or organic, has a native sulfofying flora that prevents the accumulation of elemental sulfur in the soil.

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OVERLIMING ACID SOILS[1]

A. R. MIDGLEY[2]

Various lime requirement methods carry the presumption that the soil must be neutral for the successful growth of plants, therefore, the amount of limestone recommended is the amount of calcium carbonate necessary to neutralize completely 2,000,000 pounds of soil, or an acre to a depth of about 7 inches. In practice, where lime is applied as a surface dressing and harrowed into the soil, it is doubtful if it gets mixed with more than half the required amount of soil. In this case the limed area will have received at least double its lime requirement. On grasslands where it is applied as surface dressings, the surface inch will have received several times its calculated amount of lime for quite some time

The object of this paper is to show that the overlimed area often exhibits very toxic and injurious properties to many crop plants, especially new seedlings To determine the nature and cause of this condition, certain experiments were performed in an attempt to answer the following questions· Are overlimed soils too alkaline for proper plant growth? Is there a lack of available plant nutrients? Does soluble calcium or nitrite nitrogen accumulate sufficiently to be toxic on overlimed soils?

The necessity and value of lime for many crop plants on acid soils is unquestioned However, literature is available to show that plant growth is often depressed following its usage. Blackwell (5)[3] claims that one-half the rate of lime recommended to correct the acidity gave larger yields than when the full rate was applied. Karraker (15) reports a depression from the use of lime on the Berea soil in Kentucky, but found that it was overcome in later growth. Hartwell, *et al.*, (14) show that much lime produced a marked depressive effect on lettuce, even though the soil tested slightly acid. Williams, *et al.*, (28) give data to show that lime usually did not pay the cost of its application, and in many cases it actually reduced the yield of corn, cotton, and peanuts.

Watts (26) gives an interesting account on the effect of various amounts of lime on the root growth of alfalfa. An amount of lime equal to just the lime requirement gave a better root growth than heavier additions, even though the former did not completely

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[3]Reference by number is to "Literature Cited," p. 835.

neutralize the soil acidity. Floyd (11), working with citrus trees, claims that ground limestone causes frenching and a partial defoliation of the terminal branches. Many references are available on lime-induced chlorosis, but they will not be given here because they seem to add very little to this problem.

FIG. 1.—Growth of rape on an acid clay loam with various amounts of lime. Fertilizer in the form of nitrophoska (12 24 12) and $MnSO_4$ was applied to all soils at a rate equivalent to 500 and 250 pounds per acre. 1, no lime; 2, full lime requirement added; 3, four times full lime requirement added; and 4, ground limestone without soil.

EXPERIMENTAL

Farmers and county agents have often sent in reports to the Vermont Agricultural Experiment Station to the effect that certain acid soils would not respond to lime, and in some instances they reported a marked depression for at least a year or so after its application. Since some of these soils were found to be very acid and therefore required large amounts of lime, the trouble was thought to be due, indirectly at least, to overliming injury

A sufficient amount of soil from three of these areas was obtained for liming studies in the greenhouse. According to the Jones' method, they required the following amount of lime per acre. Clay loam, 6.0 tons; Berkshire loam, 3 tons; and sandy loam, 2 tons. After thoroughly mixing various amounts of a very fine, high calcic lime, ranging from 0 to 4 times the lime requirement to each soil, they were placed in gallon jars and given an added treatment of nitrophoska (12–24–12) and manganese sulfate at an acre rate equivalent to 500

and 250 pounds, respectively. Two jars contained ground limestone without soil in order to see if it produced the same injurious effect. Since there was very little, if any, iron present in the ground limestone, 500 pounds of soluble iron phosphate were added to these jars. Rape was seeded for the first crop followed by a crop of flax. The data in Table 1 are yields of dry matter for the duplicate tests. (See Fig. 1.)

TABLE 1.—*Yields of rape and flax produced by various amounts of lime.*

Lime treatment	Grams of oven-dry material	
	Rape	Flax
No Soil		
Ground limestone	7.2	0.50
Clay Loam		
No lime	8.0	1.00
Full lime requirement	13.0	5.15
2 times full lime requirement	11.9	7.90
4 times full lime requirement	1.9	9.05
Berkshire Loam		
No lime	11.0	2.00
Full lime requirement	22.9	2.25
2 times full lime requirement	17.0	1.10
4 times full lime requirement	10.4	0.35
Sandy Loam		
No lime	14.2	2.70
Full lime requirement	18.8	3.60
2 tines full lime requirement	13.8	3.75
4 times full lime requirement	6.0	4.06

The data in Table 1 clearly show that these soils respond to lime when fertilized, provided that the lime additions are not too large. When four times the lime requirement was added to the soils, much injury resulted to the first crop. However, this was overcome with the second crop in all soils except the Berkshire loam, in which case the injury carried over into the second crop. On all of the other soils the second crop actually increased with increasing amounts of lime. This is in line with the findings of Das (7). The criticism might be offered that flax is a poor experimental plant, but it was used in this connection to detect the duration of the overliming injury because it has been found to be very sensitive to this condition. This is especially true on newly overlimed acid soils.

From the above data it is interesting to note that ground limestone without soil produced a better crop of rape than some of the overlimed soils. This was especially true with the clay loam with the highest lime requirement. To obtain further information in

regard to the nature of this injury, the following experiment was executed. Varying amounts of a high calcic limestone, between 10 and 40 mesh, were mixed with the required amount of the acid clay loam in order to give a mixture ranging from 100% limestone to 100% soil. The nine different percentages of limestone used in the experiment are shown in Fig. 2. Two series of these treatments were run in the greenhouse in which flax was used as the experimental plant. One series received no fertilizer, the other received KNO_3, $MgHPO_4$, and $MnSO_4$ at an acre rate equivalent to 300, 500, and 200 pounds, respectively. No yield data were obtained because the plants on the heavily limed soils soon died. However, a picture (Fig. 2) shows the results very clearly.

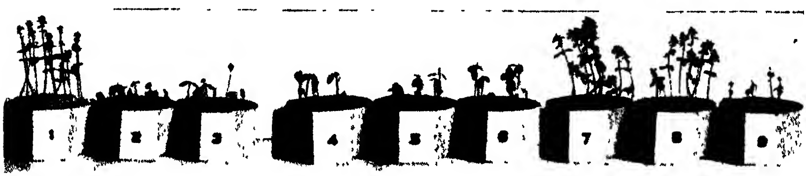

FIG. 2.—Growth of flax on lime-soil mixtures ranging from 100% lime to 100% soil. They were also fertilized with KNO_3, $MgHPO_4.3H_2O$, and $MnSO_4.4H_2O$ at an acre rate equivalent to 300, 500, and 200 pounds, respectively. 1, 100% lime, no soil; 2, 75% lime, 25% soil; 3, 50% lime, 50% soil; 4, 25% lime, 75% soil, 5, 10% lime, 90% soil; 6, 5% lime, 95% soil; 7, 1% lime, 99% soil; 8, 0.5% lime, 99.5% soil; and 9, no lime, 100% soil.

No significant difference was noticed between the fertilized and the unfertilized series. This would indicate that the injury was not due to a lack of available plant nutrients. Since better growth resulted on limestone without soil than an equal mixture of the two, it would indicate that the increase in pH from the use of much lime is not the cause of the injury.

To obtain added information relative to the effect of lime on the root growth of flax and rape, an experiment was performed in which the upper and lower halves (3 inches) of a soil contained in the same jar received two rates of calcium carbonate.

The lime-soil mixture in each case was separated by a single layer of waxed cheese cloth. This helped to separate the two treatments, yet it allowed the roots free access to penetrate into the second depth. The treatments were run in duplicate and grown in the greenhouse until the badly injured plants began to deteriorate. The aerial portions were then removed and the roots in the two areas carefully harvested. These results are presented in Table 2.

TABLE 2.—*Root growth of flax and rape in upper and lower 3 inches of soil with various liming treatments.*

Soil	Lime treatment in upper and lower 3 inches of soil*	Weight of roots in each depth, grams	Total weight of roots, grams
	Flax		
Clay loam.	½ lime requirement	3.60	4.87
	4 times full lime requirement	1.27	
Clay loam.	4 times full lime requirement	1.01	2.25
	½ lime requirement	1.24	
Berkshire loam	Lime requirement	3.11	4.12
	4 times full lime requirement	1.01	
Berkshire loam	4 times full lime requirement	1.27	2.50
	Lime requirement	1.23	
Sandy loam	Lime requirement	3.19	4.37
	4 times full lime requirement	1.18	
Sandy loam	4 times full lime requirement	.76	2.50
	Lime requirement	1.74	
	Rape		
Clay loam.	½ lime requirement	3.80	5.00
	4 times full lime requirement	1.20	
Clay loam	4 times full lime requirement	1.23	1.75
	½ lime requirement	0.52	

*First amount in each case for upper 3 inches; second amount for lower 3 inches.

The data presented in Table 2 clearly show that heavy liming is injurious to the root growth of both flax and rape. When the excess lime was placed in the upper 3 inches of soil, many of the plants died before their roots could reach the more favorable lightly limed area below. In case of the clay loam, the only plants which succeeded in passing through the heavily limed area were those around the outer edge of the soil, next to the container. This may have been due to better aeration or to a less concentrated solution of lime in this area. Fig. 3 shows the influence of the two rates of lime on the root growth of rape.

SOILS AND PLANTS MOST SUSCEPTIBLE TO OVERLIMING INJURY

Light mineral soils that are somewhat acid and have not been cultivated for several years usually show the greatest amount of injury when heavily limed. Extensive greenhouse experiments, however, have shown that both peat and mineral soils are injured by excessive liming, provided they are sufficiently acid. Neutral or basic soils heavily limed never exhibit this same injury unless they are first made acid either by electrodialysis or leaching with a weak acid.

The plants found to be most susceptible to this overliming injury

were flax, rape, and mustard. However, alfalfa, most of the clovers and even lettuce, which is a high-lime-loving plant, were all greatly depressed and injured.

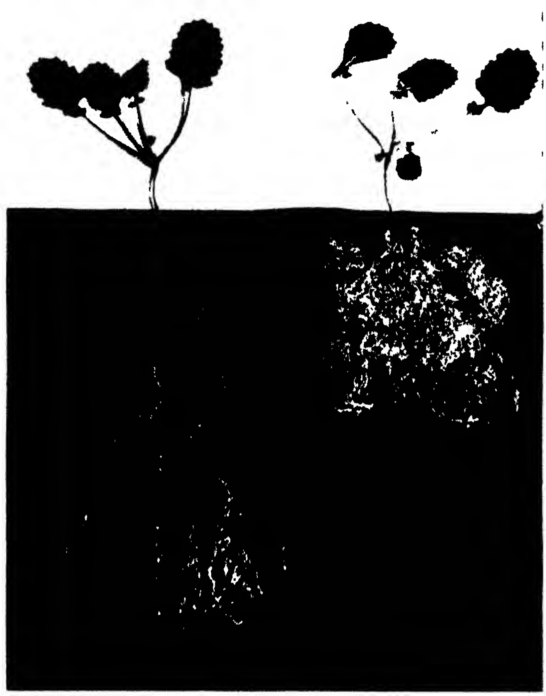

FIG. 3.—Distribution of roots on rape plants grown in clay loam with two rates of lime. Left, four times lime requirement, upper 3 inches; one-half lime requirement, lower 3 inches of soil. Right, one-half lime requirement, upper 3 inches; four times lime requirement, lower 3 inches of soil.

The first symptom of plant injury in severe cases was a short stubby and somewhat knotty root growth which soon turned brown in color. Flax seemed to be injured most and in many cases the epicotyl would not emerge beyond the cotyledons, but the latter would enlarge for some time, and finally the whole plant would die. The leaves on the injured rape plants were short and had a tendency to curl inward. Clover and alfalfa plants showed a general depression and in most cases no nodules were produced. In the experiments which follow, flax and rape plants were used to study the nature of this injury because they grow rapidly and have proved to be good indicators of an overlimed condition.

ARE OVERLIMED SOILS TOO ALKALINE FOR PROPER PLANT GROWTH?

When soils are heavily limed they become somewhat alkaline in reaction, but much literature is available to show that this is not directly injurious to most crop plants. The recent work of Das (7), Pierre (19), and Emmert (9) support this.

Calcium silicate is as effective as calcium carbonate in reducing soil acidity, yet the former was never injurious to flax or rape at concentrations and pH values greatly in excess of the injured calcium carbonate treated soils. This information, together with the fact that neutral soils heavily limed never produce the same characteristic injury, would indicate that basicity, as such, is not the major cause of this trouble.

IS OVERLIMING INJURY CAUSED BY A LACK OF AVAILABLE PLANT NUTRIENTS?

To determine the effect of fertilizers and other materials in reducing overliming injury, an experiment was performed in which various rates and forms of potassium, magnesium, manganese, phosphorus, nitrogen, and iron were applied singly and in combination to an overlimed soil. The soil used was the above-described acid clay loam. This was heavily limed with pure calcium carbonate by applying four times its full lime requirement. After adding the various fertilizing materials to samples of this heavily limed soil, they were seeded to flax and grown in the greenhouse until the plants began to deteriorate. No yield data were obtained because the growth in all cases was very poor and similar to the overlimed, unfertilized checks which seldom produced sufficient growth to be harvested. Similar experiments have been tried on other soils with substantially the same results, except on soils that were not greatly injured with lime. In these cases, however, the necessary fertilizers were found to be beneficial. These experiments would indicate that overliming injury is not due to a lack of available plant nutrients. This may be expected because the injury seems to be of a toxic nature since the nutrients already present in the seeds should provide a fairly good growth.

IS THERE AN EXCESS OF SOLUBLE CALCIUM ON HEAVILY LIMED SOILS AND IS THIS THE CAUSE OF THE INJURY?

Much injury always resulted when heavy applications of lime were used on the acid clay loam. If this injury was due to soluble calcium, we would expect to find more of it in the heavily limed soil than in the same soil lightly limed, since the latter was never injurious. To determine the amount of soluble calcium in this soil after receiving

two rates of lime, the following experiment was performed. Pure calcium carbonate equivalent to one-half and four times the lime requirement was added to 100 grams of acid clay loam. The lime and soil were thoroughly mixed together and after they had been moistened for 48 hours, they were slowly leached with 300 cc of distilled water and the filtrate analyzed for calcium.

TABLE 3.—*Soluble calcium in soil and sand after various liming treatments.*

Material and rate of lime used	Mgs. of calcium in 300 cc of filtrate
Acid clay loam with ½ lime requirement	36.30
Acid clay loam with 4 times full lime requirement	65.30
Quartz sand and lime, equal to 4 times full lime requirement. .	4.12

The results are presented in Table 3 and show that nearly twice as much soluble calcium is present on the heavily limed acid soil as compared with the same soil lightly limed. These results indicate that soluble calcium is associated with overliming injury since crop growth was always injured on this soil when heavily limed. This is in agreement with Truninger (24) and Prianischnikow and Golubeu (20) who claim that soluble calcium is the major cause of overliming injury.

In order to see whether or not calcium bicarbonate was the cause of the injury, an experiment was performed in which sand and neutral soil cultures, with and without lime, were seeded to flax and constantly leached with a saturated solution of calcium bicarbonate. A similar set, including ground limestone, was aerated 6 or 8 times each day with carbon dioxide. The gas was emitted under pressure through a small hole in the bottom of each jar. The plants were not grown to maturity, but in no case did they exhibit the toxic growth which was characteristic of the check or the heavily limed acid soil. Other soluble forms of calcium, including phosphates, nitrates, sulfates, and chlorides, gave similar results. It would seem, therefore, that the observed injury is not entirely due to soluble calcium compounds.

DO NITRITES ACCUMULATE SUFFICIENTLY TO BE INJURIOUS IN OVERLIMED SOILS?

A considerable amount of literature is available to show that nitrite nitrogen accumulates on heavily limed soils. Uspensku (25) shows that care must be taken to avoid overliming acid soils, because at or near the neutral point the nitrifiers are at their best, and with an in-

crease in alkalinity the denitrifiers increase. Arnd (3) claims that there is an energetic reduction of nitrates to nitrites with a loss in total nitrogen on overlimed soil. Fraps and Sterges (12) and Robinson (21) also show that nitrites are increased on heavily limed or basic soils.

Some literature shows that nitrite nitrogen is injurious to crop growth. Gerlach (13), Schultz (23), and Kellner (16) showed that nitrite nitrogen was inferior to nitrate nitrogen and in many cases proved to be toxic when used in large quantities. Densch (8) attributed the injury from excessive liming to nitrite and nitraso compounds. Bobko, *et al.*, (6) claim that bicarbonates, nitrite, and ammoniacal nitrogen accumulate sufficiently on overlimed soils to be injurious.

To determine the effect of lime on the production of nitrite nitrogen in the acid clay loam, the following experiment was performed.

Two hundred grams of the soil were placed in Buechner funnels with various amounts of lime. One series was kept moist for 20 days, and was then leached once with 200 cc of distilled water. The other series was leached with 200 cc of water each day for 20 days. The total milligrams of nitrite nitrogen produced within the 20-day period from each treatment are given in Table 4.

TABLE 4.—*Effect of lime and leaching on the production of nitrite nitrogen in 200 grams of soil, filtrate analyzed after each leaching of 200 cc.*

Lime treatment	Total mgs of nitrite nitrogen produced within 20 days	
	Kept moist 20 days then leached once with 200 cc water	Leached daily with 200 cc of water
Clay loam, no lime	0.00	0.80
Clay loam, ½ lime requirement .	0.12	6.20
Clay loam, 4 times full lime requirement	2.40	97.96

The data in Table 4 show that heavy liming greatly increased the production of nitrite nitrogen. Since there is more than 16 times as much nitrite nitrogen on the soil heavily limed as on the same soil lightly limed, it would seem that this may be the cause of overliming injury.

To study this in more detail and to determine whether or not the characteristic injury could be produced from nitrites, the following experiments were performed. Soil and sand cultures, with and without small amounts of lime, were seeded to flax and leached daily with 400 p.p.m. of nitrite nitrogen as calcium nitrite. In no case were the

plants injured anything like the checks or similar soils heavily limed and leached with water. Preliminary experiments, however, showed that high concentrations of nitrite nitrogen produced some injury, yet the concentrations used in this experiment were far in excess of those found in overlimed soils at any one time. In another experiment, calcium nitrite at a rate equivalent to 2,000 pounds per acre was used on two soils after they had received various liming treatments. They were then seeded to flax and grown in the greenhouse until the plants on the overlimed soils began to die. The yields of dry matter produced from the duplicate treatments are given in Table 5.

TABLE 5.—*Effect of calcium nitrite, equivalent to 2,000 pounds per acre, on the growth of flax.*

Lime treatment	Average grams dry matter per jar	
	Without calcium nitrite	With calcium nitrite
Clay loam		
½ lime requirement	2.00	2.74
4 times full lime requirement	0.28	0.36
Berkshire sandy loam		
½ lime requirement	2.90	2.90
4 times full lime requirement	1.80	2.02

While the data in Table 5 clearly show the depressive effects from the use of much lime, yet they indicate that nitrite nitrogen is not the cause of the injury; in fact, it slightly increased growth.

Repeated observation and chemical analysis have shown that neutral soils heavily limed often contain more nitrite nitrogen than acid soils similarly limed, yet the former never exhibit the same toxic or injurious properties to plant growth. From these results it would seem that nitrite nitrogen is not the major cause of the observed injury, even though it is associated with overliming.

TREATMENTS WHICH REDUCE OVERLIMING INJURY

Certain leaching and aging treatments often reduce overliming injury. Additions of organic matter, such as manure, alfalfa meal, and straw are also valuable in this respect. The only chemical found thus far to reduce this injury is calcium silicate. Details of experiments concerning these materials are given below.

Leaching experiments—Overliming injury was found to be greatly reduced by slowly leaching the soil with rain water while the plants were growing. This indicated that the injurious material was actually removed from the soil during the leaching process.

To study this in more detail, a large amount of freshly overlimed acid soil was occasionally leached with a sufficient amount of water to irrigate or supply the needs of plants growing on pure sand. These results showed that the injurious material from the overlimed soil was not transferred in sufficient quantity to be injurious to the sand cultures; in fact, better growth was produced with the filtrate than without it. This would indicate that the solubility of the injurious material is so low that it can not be removed in sufficient quantity to injure crop growth, or else it is easily destroyed by the atmosphere during its transference.

Aging experiments—With age, an overlimed soil gradually loses its injurious effects. In some experiments the depressive effect of excess lime was completely overcome with the second crop, and in many cases the yield of the second and third crops actually increased with increasing amounts of lime. With some very acid sandy loam soils, however, crop growth continued to be depressed until after the third or fourth crop was harvested. Attempts were made to determine what takes place during this aging process. The most significant finding was the change in soluble calcium. After aging an overlimed soil by a process of wetting and drying 10 times, the water-soluble calcium was reduced fully one-half, compared with the moist but unweathered sample. As the aging continued, the soluble calcium was reduced but never became as low as the limestone itself. These results would indicate that overliming injury is associated with soluble calcium.

Effect of calcium silicate—There is much literature available which shows that calcium silicate is as good as, if not better than, a corresponding amount of calcium carbonate on acid soils The investigations of Mooers (18), MacIntire and Willis (17), Barnette (4), and Ames (2) show this to be true. Schollenberger (22) found that silica compounds with calcium carbonate gave better crop yields than calcium carbonate alone. This is somewhat in agreement with the present investigation and the data in Table 6 clearly show the value of calcium silicate in this respect.

Probably the most significant finding in Table 6 is the value which calcium silicate has in reducing the injury from an already overlimed soil. When an excess amount of calcium carbonate was used, the plants were seriously injured, but when an equivalent amount of calcium silicate was added to the overlimed soil, the injury was greatly reduced, in spite of the fact that the soil was slightly more basic. Smaller additions of calcium silicate also proved to be beneficial in reducing the injury, but the maximum reduction was usually

obtained only when the calcium silicate was equivalent to the calcium carbonate. While the results presented are for one soil type only, they are representative of similar results on several other acid soils.

TABLE 6.—*Plant growth and pH from the use of calcium carbonate, calcium silicate, and a mixture of the two on an acid clay loam.*

Treatment	Grams of oven-dry matter produced	pH of soil after cropping
½ lime requirement as $CaCO_3$	4.40	6.20
½ lime requirement as $CaSiO_3$	4.80	6.15
4 times full lime requirement as $CaCO_3$. ..	1.20	7.75
4 times full lime requirement as $CaSiO_3$	4.00	7.80
Mixture of $CaCO_3$ and $CaSiO_3$ each equivalent to 4 times full lime requirement. ...	3.80	7.90

Effect of organic matter—To determine the effect of organic matter in reducing overliming injury, air-dried cow manure, alfalfa meal, and oat straw were applied to the acid clay loam at a rate equivalent to 10 tons per acre. For comparison, various amounts of lime with fertilizer were also used. Nitrophoska (12-24-12) and manganese sulfate at a rate equivalent to 500 and 250 pounds, respectively, were applied to all jars except those receiving manure and alfalfa meal. The average yields of air-dried rape produced from the duplicate treatments are given in Table 7.

TABLE 7.—*The effect of manure, alfalfa meal, and straw in reducing overliming injury on the acid clay loam.*

Treatment	Grams of dry rape harvested
No lime or fertilizer. . . .	9.2
Full lime requirement + fertilizer. . .	15.0
4 times full lime requirement + fertilizer . . .	2.0
4 times full lime requirement + fertilizer + straw	19.4
4 times full lime requirement + manure. .	20.0
4 times full lime requirement + alfalfa meal.	21.3

From the data presented in Table 7 it is readily seen that the injurious effects of overliming are not only overcome by the use of organic matter, but that the yields are greatly increased.

It is not yet known just how the organic matter reduces this injury. However, it is known that organic matter improves the biological and physical condition of the soil, together with the fact that it is a good buffer toward injurious substances. From a practical standpoint these findings are important and indicate that liberal additions of stable or green manures should aid in getting a good "catch", if they are to be seeded immediately after liming.

SUMMARY

The primary object of these investigations was to study why crop growth is often delayed and even depressed from liberal applications of lime on acid soils. While only laboratory and greenhouse results are available at the present time, yet the following statements appear to be justified by the data obtained.

Crop growth is often injured when fine high-calcic limestone is applied to very acid soils in excess of their lime requirement. This condition may also result when the calculated amount of lime is not worked into the proper soil depth. In this case, the limed area will have received several times its lime requirement for quite some time.

The plants found to be most susceptible to injury on overlimed acid soils are flax, rape, mustard, alfalfa, and most of the clovers.

The first symptom of injury is the brown, stubby, and somewhat knotty root growth In severe cases with flax, the epicotyl does not emerge beyond the cotyledons, but the latter enlarges for some time, then finally, the whole plant dies.

Overliming injury can be produced only on heavily limed acid soils. Neutral or basic soils similarly limed never exhibit the same injury.

High pH values due to excessive lime additions do not seem to be the major cause of the trouble.

Liberal applications of various plant nutrients reduced the injury very little, if any.

A considerable amount of soluble calcium in the form of bicarbonate was found on heavily limed acid soils. It would seem, therefore, that injury was associated with soluble calcium, yet it could not be artificially produced with soluble calcium salts or bicarbonates.

Nitrite nitrogen increased with increasing amounts of lime, yet it is very doubtful if it accumulated sufficiently to be injurious.

Overlimed soils gradually lost their injurious effects with age. The injury was completely overcome on some soils by the time the first crop was removed, but with others two or three croppings were necessary before it was completely overcome.

No injury could be produced with calcium silicate, even though it proved to be as effective as calcium carbonate in reducing soil acidity.

Calcium silicate is very beneficial in reducing the injury produced by overliming with calcium carbonate.

Large additions of organic matter, such as straw, alfalfa meal, and manure, were found to be very effective in reducing overliming injury. From a practical standpoint this finding is important because it indicates that a liberal addition of green or stable manure should be applied to the soil if immediate liming and seeding are necessary.

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NOTES

UNIT DAYS OF GRAZING

The beginning of experimental work in pasture investigations is so recent that little has been done in the formulation of terms to describe the factors concerned in this field. There are a number of terms now in use which are unsuited for accurate descriptions and which may convey a different meaning in various publications. Perhaps the most conspicuous examples of this kind are the terms "cow days," "cattle days," or "pasture days" of grazing.

The need for a term which will express the idea of quantity of grazing supplied by different pastures, or for the same pasture under different methods of management or fertilizer treatment, has been apparent in all of the articles contributed by investigators of this subject. While there is a rather general understanding that "cow days of grazing" or "cattle days of grazing" carry a meaning of animal unit days, the terms in themselves do not imply exactly this and it has not been the practice in every case to reduce the data to unit days.

The expression "cow days of grazing" means of course that a mature or adult cow has been provided an opportunity to graze on the pasture for the indicated number of days. The expression "cow days" is objectionable from the standpoint of the beef cattle producer or experimenter because in many cases the animals are males rather than females. "Cattle days of grazing" or "pasture days" are objectionable because they do not indicate in themselves that the animals grazed were adults. The use of such terms does not give the reader assurance that the cattle were adults and the writer assumes no obligation for an implication of this kind when he uses them. Some of the animals may have been less than a year old.

We wish to propose, therefore, as a substitute for "cow days," "cattle days," and "pasture days," the term "unit days." The term "unit days of grazing" has several factors of advantage. It is short,

carries in itself a direct indication of its meaning, and when its use becomes general the reader will understand immediately that "unit days of grazing" means one day of grazing for an animal unit. By the use of such a term the author accepts an obligation to translate his results into recognized official units. Such an obligation every author should be prepared to assume and thereby convey to the reader a more exact idea of what his data mean.

The term animal unit as it has been used in publications is defined as one adult of cattle, horses, or mules, five hogs, or seven sheep or goats. (See page 321, U.S. Dept. of Agriculture Yearbook for 1923.) A calf, colt, pig, lamb, or kid is considered as one-half of an adult animal in calculating its feed requirements. In grazing studies, however, a more exact division of cattle is proposed herewith to the effect that the animal units, so far as cattle are concerned, be calculated on the following basis:

Animal classes	Season of birth	Age in months while grazing	Approximate initial weight in pounds	Animal units %
Calves	Spring	2– 8	150	25
Calves. . .	Fall	8–14	350	45
Yearlings. ..	Spring	14–20	450	60
Long yearlings.	Fall	20–26	625	75
Two-year olds.	Spring	26–32	750	85
Three-year olds	Fall	32–38	850	95
Adults	———	38+	1,000	100

H. N. Vinall, *Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.*, and A. T. Semple, *Bureau of Animal Industry, U. S. Dept. of Agriculture.*

CONVENIENT EQUIPMENT FOR TAKING THE GREEN WEIGHTS OF ALFALFA PLATS

In obtaining yields of forage crops it is quite generally agreed that greater accuracy is assured where the material is weighed green and samples taken immediately for moisture determination. The desirability of speeding up the work as much as possible is evident and various time-saving devices have been adopted. Fig. 1 shows the equipment designed to speed up the work and to eliminate considerable labor in harvesting the experimental plats of alfalfa at the Kansas Agricultural Experiment Station, Manhattan, Kan.

The carrier is made with two pieces of flat iron strips (1 x 5 16 inch) and 15 5/16-inch round rods 7½ feet in length riveted at each end to the flat iron strips and spaced 3 inches apart. The round bars are turned up at the rear, forming the basket; while the two outside rods, which are 6 inches shorter than the others, form the sides. An upright slot is attached at each end of the cutter bar so that the carrier is readily adjusted by dropping into the slots the ends of the flat iron strip at the front of the carrier. The slots should be so placed that the carrier fits rather closely to the rear of the cutter bar.

As the hay is cut it falls onto the carrier and is conveyed away from the cutter bar to the rear of the carrier by the stubble underneath.

At the end of each plat a canvas is spread back of the carrier and the hay is dumped on it by lifting the front of the carrier from the slots and tilting backward. The cutter bar of the mower used in this case is 4 feet wide and the carrier holds 100 to 120 pounds of green alfalfa easily or 150 pounds by crowding. No loss of hay results, even when the crop is light.

The weighing equipment consists of a 1 5/8 inch gas pipe bent as in Fig. 1 and set over an iron post which is bolted to the mower tongue. As soon as the green material is weighed, moisture samples of approximately 10 pounds are taken and weighed behind the wind break shown in the picture.

FIG. 1.—Equipment for collecting and weighing alfalfa on experimental plats

The plats on which this equipment is used are 7 feet wide and 104 feet long, being separated by 1-foot alleys. The yield is based on the 4-foot swath taken lengthwise of the plat, thus eliminating the border effect.—C. O. GRANDFIELD, *Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating with Kansas Agricultural Experiment Station, Manhattan, Kan.*

AGRONOMIC AFFAIRS

THE TWENTY-FIFTH ANNUAL MEETING OF THE SOCIETY

The twenty-fifth annual meeting of the Society will be held at the Willard Hotel in Washington, D.C., on Thursday and Friday, November 17 and 18. The program will comprise a meeting of the Crops Section under the leadership of Dr. R. J. Garber and a meeting of the Soils Section under the leadership of Professor M. F. Miller. The Sectional programs will be given Thursday morning and during both the morning and afternoon sessions on Friday, and will include both symposia and open programs. Printed abstracts of papers to be presented on these programs will be available at the registration desk.

Special recognition of the Society's twenty-fifth anniversary will be provided for on Thursday afternoon, with a series of invited

papers on appropriate topics. The annual dinner will be held Thursday evening and will be followed by the President's address, reports of officers and committees, and other items of business.

Reduced railroad fares will be available to members of the Society attending the meeting. Certificates should be obtained at time of purchasing one-way tickets to Washington. These certificates will be validated at the registration desk and will then make possible the purchase of a return ticket at one-half the regular fare.

THE PROPOSED NEW CONSTITUTION

The proposed new constitution of the Society, incorporating the recommendations of the special committee on the reorganization of the Society as reported at the last annual meeting, is printed below. This proposed constitution will be presented to the Society for final action at the annual meeting in November.

PROPOSED CONSTITUTION OF THE AMERICAN SOCIETY OF AGRONOMY

NAME

ARTICLE I. The name of this organization shall be The American Society of Agronomy.

OBJECT

ARTICLE II. The object of the Society shall be the increase and dissemination of knowledge concerning soils and crops and the conditions affecting them.

MEMBERSHIP

ARTICLE III. The Society shall be made up of four classes of members (1) Honorary; (2) Fellows; (3) Active; (4) Associate. Honorary members may be chosen by the Society from among distinguished colleagues. Fellows may be chosen by the Executive Committee from the members whose professional records warrant recognition Active members shall be those persons who are interested in the objects of the Society. Associate members shall be those who are interested in the objects of the Society but who do not wish to become active members. They may participate fully in all meetings and may offer papers for publication in the Journal of the Society, but they shall not receive the Journal nor have a vote in the general Society except on matters pertaining to the subsection in which they are interested.

SECTIONS

ARTICLE IV. The Society shall be divided into two organic sections—a Soils Section and a Crops Section—and each section shall organize such subsections as it may see fit.

ARTICLE V. Any group of members may, with the approval of the Executive Committee, organize a local or regional section or a student section of the Society. The members of such sections may become active or associate members of the Society and will be entitled to all the privileges which pertain to those classes of members. These

sections may make their own rules for membership. Student sections at various institutions, if they so desire, may unite to form a *National Student Section* of the Society, to meet at the time of the annual meeting of the Society, elect officers, arrange a program, and adopt such by-laws as may be desired, provided that such by-laws do not conflict in any way with the constitution and by-laws of the Society.

OFFICERS

ARTICLE VI. The officers of the Society shall consist of a president, a vice-president, a secretary-treasurer, and the Editor of the JOURNAL.

Each of the two sections of the Society shall provide a chairman, who shall be chosen by the individual section. The sections may select such additional officers as they may desire.

The Executive Committee of the Society shall consist of the President, the Vice-President, the Secretary-Treasurer, the Editor, and the Chairmen of the two organic sections of the Society.

DUTIES AND TERMS OF OFFICE

ARTICLE VII. The duties of these officers shall be those usually pertaining to their respective offices. All officers shall be elected at the annual meeting of the Society. The term of office of the president shall be for one year or until his successor has been elected. The term of the vice-president shall be for one year and he shall automatically succeed to the presidency. The vice-president shall be chosen alternately from the two organic sections of the Society. The terms of the chairman of the two sections of the Society shall be for one year and they shall be elected at the annual sectional business meeting Sectional chairmen shall be eliminated from consideration as nominees for the vice-presidency.

The Secretary-Treasurer and the Editor shall be appointed by the Executive Committee.

The Executive Committee shall act upon all matters arising between meetings of the Society.

MEETINGS

ARTICLE VIII. When not determined by vote of the Society, the time and place of meetings shall be decided upon by the Executive Committee.

AMENDMENTS

ARTICLE IX. This constitution may be amended by a two-thirds vote of the members present at any regular meeting, announcement of the proposed amendment having been made at least ten days before such meeting. The Executive Committee may propose amendments at any time between meetings and the same shall be accepted or rejected by a two-thirds vote of the members who mail their ballots within thirty days after the notice of the proposed amendment was sent to them. Any twenty members may initiate a proposed amendment which shall then be submitted by the Executive Committee to a vote of the Society.

BY-LAWS

1. The annual dues of each active member and fellow shall be five dollars ($5.00) which shall be paid on or before January 1 of the year for which membership is held.

   Honorary members shall be exempt from the payment of dues but shall receive the Journal.

   Associate members shall be exempt from the payment of dues.
2. Any active member or fellow in arrears on March 1 for dues for the current year shall be dropped from the rolls of the Society. Reinstatement to membership may be accomplished without action of the Society upon payment of such arrears.
3. One meeting of the Society shall be held every year if practicable. Special meetings and joint meetings may be arranged by the Executive Committee.
4. The annual meeting of the Society shall consist of one or two general sessions and sectional sessions in Soils and Crops.
5. A quorum at the annual meeting for the transaction of business shall consist of fifteen members.
6. The standing committees of the Society in addition to the Executive Committee shall consist of
   (1) A nominating committee which shall include the President of the Society, who shall be chairman, and two additional members from each of the two organic sections to be appointed by the sectional chairmen.
   (2) An auditing committee.
   (3) A committee on resolutions.
   (4) A program committee, consisting of the President and Vice-President who shall arrange the programs of the general sessions. The sectional chairman shall organize the programs for their respective sections.
7. The Special committees of the Society shall consist of
   (1) A Committee on Agronomic Terminology
   (2) A Committee on Varietal Standardization and Registration.
   (3) A Committee on Standardization of Field Experiments.
   (4) A Committee on Education in Agronomy.
   (5) A Committee on Fertilizers.
   (6) A Joint Committee on Fertilizer Distributing Machinery.
   (7) A Joint Committee on Corn Borer Investigations.
   (8) A Committee on the Chilean Nitrate of Soda Nitrogen Research Award.
   (9) A Committee to represent the Society on the National Advisory Council on Radio in Education.
   (10) A Committee on Land Utilization.
   (11) A Committee on Soil Erosion.
   (12) A Committee on Organization of a National Student Section of the Society.
   (13) A Committee on Publications of the Society.
   (14) An Advisory Editorial Committee.

   Additional special committees may be appointed by the President as he may deem desirable.
8. These by-laws may be amended by a two-thirds vote of the members present at any regular meeting of the Society.

THE INFLUENCE OF FERTILIZERS ON CROP QUALITY

A bibliography of 389 titles with a discussion of the findings reported in the literature through 1931 of the influence of fertilizers on crop quality has just appeared as Section II of the *Proceedings* of the Eighth Annual Convention of the National Fertilizer Association held at White Sulphur Springs, W. Va., June 6 to 8. The review has been prepared by Dr. Burt L. Hartwell under a grant from the National Fertilizer Association and with the cooperation of the Committee on Fertilizers of the Society. The bibliography and discussion, together with an index to the latter, comprise 60 pages. Wide distribution of the *Proceedings* has already been made among experiment station workers and others and a number of separates of the review have also been distributed by the National Fertilizer Association. A limited supply of the separates has been placed in the hands of President P. E. Brown and members of the Committee on Fertilizers, while they may also be obtained from Mr. Charles J. Brand, Executive Secretary and Treasurer of the National Fertilizer Association, who with Mr. H. R. Smalley, has represented the Association in the preparation and publication of the bibliography.

In a foreword to the review, it is pointed out that most experiments with fertilizers on crops have had to do with learning how best to increase yields and financial returns rather than to discover how the treatment affected the quality of the crop. However, by analyzing the idea conveyed by the word "quality" and by studying the literature with these conceptions in mind, a considerable literature on the subject has been uncovered. While it is realized that the present review is probably incomplete, the hope is expressed that it will serve as a nucleus to which will be added material that has been overlooked and new contributions to the subject as they may appear.

NEWS ITEMS

THE DIVISION of AGRONOMY and PLANT GENETICS, University of Minnesota, recently conferred the following graduate degrees: Doctor of Philosophy, to S. C. Salmon, Agronomist, and to E. R. Ausemus, Association Agronomist, both of the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C.; and Master of Science to E. R. Clark, D. M. Hall, W. E. Haines, C. Stuart Christian, and Carl Borgeson.

R. S. DUNHAM of the Northwest School of Agriculture, Crookston, Minn., is pursuing graduate work in Agronomy and Plant Genetics, University of Minnesota.

W. M. MYERS, graduate of the Kansas State Agricultural College, has been appointed to a graduate assistantship in Agronomy and Plant Genetics at the University of Minnesota.

DR. H. K. HAYES, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, has been granted a leave of absence for the academic year to become Acting Professor of Plant Breeding at Cornell University. During the absence of Dr. Hayes, Dr. H. K. Wilson will be Acting Chief of the Division.

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RE-ASSEMBLING THE FACTORS FOR AWNS AND FOR SPIKE DENSITY IN SEVIER X FEDERATION WHEAT CROSSES AND BACK CROSSES[1]

GEORGE STEWART[2]

Some unusual awn segregations have been previously obtained in wheat variety crosses at the Utah Agricultural Experiment Station. One of these, which has repeated itself at least 20 or 30 times, was the occurrence of two factors for awns first studied in crosses involving Sevier and Federation wheats. In back crosses, also, the same behavior has been found and clearly established. One or two workers using other varieties have orally questioned not only the occurrence of two factors, but also the separation of the resulting awn classes with reference to the range of variations included in each class.

One segregation was obtained which seemed to indicate linkage between these two factors in the cross of Sevier x Federation.[3] Later, one pure-breeding segregate from a Sevier x Dicklow cross showed some evidence of linkage when this segregate was crossed with Federation.[4] On the other hand, several other crosses of a somewhat similar nature revealed no evidence of such linkage.[5] The writer, therefore, came to doubt the suggested linkage and planned a series of crosses to test it as well as the awn classes themselves.

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director March 4, 1932. Received for publication March 8, 1932.

[2]Formerly Agronomist, Utah Agricultural Experiment Station; now Senior Forest Ecologist, Intermountain Forest and Range Station, U. S. Forest Service, Ogden, Utah.

[3]STEWART, G. Correlated inheritance in wheat. Jour. Agr. Res., 33:1163–1192. 1926.

[4]STEWART, G. Inheritance of awns in crosses involving Sevier and Federation wheats. Jour. Amer. Soc. Agron., 20: 160–170. 1928.

[5]STEWART, G., and HEYWOOD, D. E. Correlated inheritance in a wheat cross between Federation and a hybrid of Sevier x Dicklow, Jour. Agr. Res., 39: 367–392. 1929.

The test crosses involved (1) a repetition of the original cross (Sevier x Federation) itself; (2) a back-cross of the awnless parent (Federation) on the F_1 of the two parents; and (3) a series of crosses between the segregates themselves and between the segregates and the awnless parent (Federation). Since this work was not of high "economic" importance, it had to be done only as opportunity presented itself and after the economic wheat improvement work was cared for. One lot of the material, lost in the year of the cross due to rodent injury, included the back-cross of Federation on the F_1 between the two parents. Due to the writer's change of work it cannot now be repeated. The other studies have been completed and the data are herewith presented. These data corroborate the awn groups used earlier, but throw further doubt on the linkage between the two factors for awns. The data from the repeated original cross are presented first, followed by the data from the crosses between segregates themselves and between the segregates and Federation.

Head density inheritance, which was also unusual, is studied in the repeated original cross and in a back cross between one of the compact segregates and the parent having lax spikes, Federation.

EXPERIMENTAL PROCEDURE

The Sevier 59 x Federation cross has been studied at Logan, Utah, during the last few years. Several families were grown in F_1 and F_2. The most vigorous F_2 family, consisting of 448 plants, was chosen to continue the cross. The F_3 progenies were seeded according to spike-density classes of the F_2 plants. There were four true-breeding awn groups classified for convenience as awn classes 1, 2, 3, and 4. Awn class 1 consisted of short beaks with an occasional short apical awn, similar to the Federation parent. Plants belonging to awn class 2 contained awns of intermediate length located principally in the upper third of the spike. For this character they resembled rather closely the F_1 plants. Awn class 3 consisted of somewhat longer apical awns than occurred in awn class 2 with short awns nearly to the base of the spike. There was a distinctly different appearance between awn classes 2 and 3. The fully awned plants were classed as awns 4, resembling the Sevier 59 parent in this character (Fig. 1).

Spike density was obtained by a measurement of 10 internodes on a leading spike of each plant for which purpose the extreme upper and lower spikelets were avoided as they are more variable in length than the central portion. The awns were not only classified by observation, but one of the longer awns of each plant was measured.

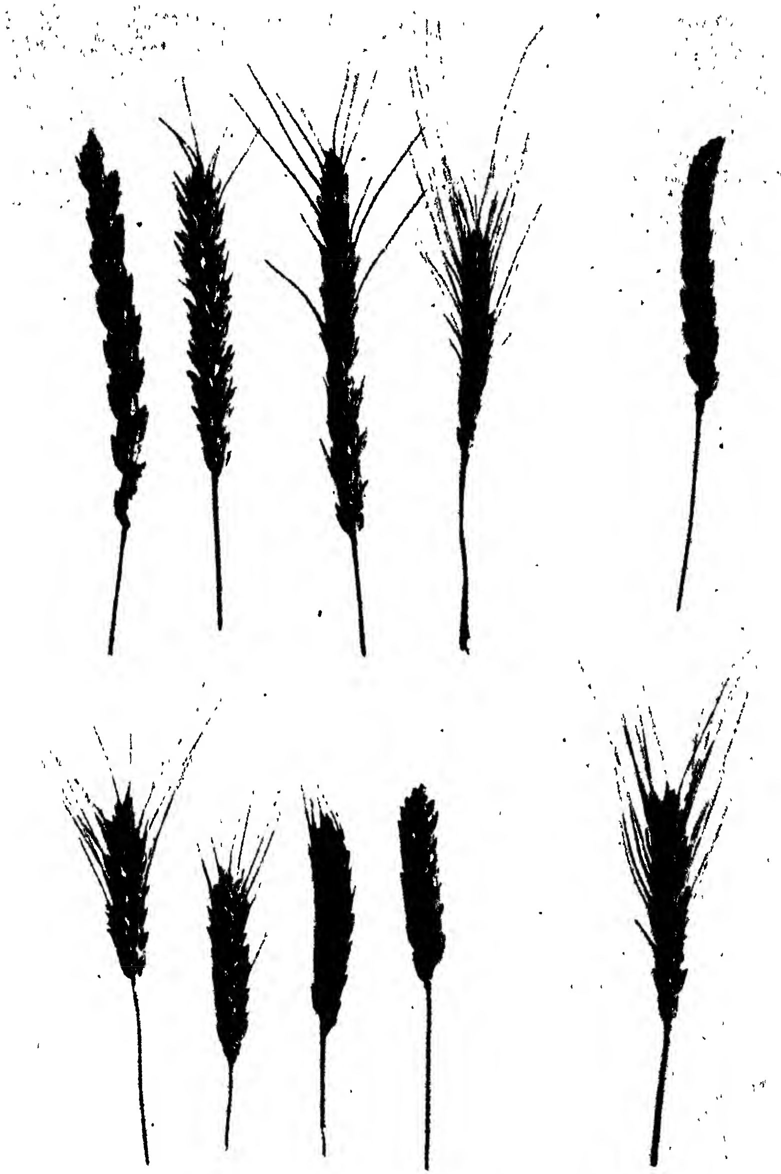

FIG. 1.—The four classes of awns in the Federation x Sevier cross. On the extreme right are the two parents, Federation (above) and Sevier (below). *Above, left to right:* Awn class 1 (awnless); awn class 2 (short awn tips); awn class 3 (short tip awns in lower half of spike and part-length awns in upper half); and awn class 4 (fully awned). *Below, left to right:* Awn class 4; awn class 3; awn class 2, and awn class 1.

The breeding behavior of the F_2 plants was determined by studying the F_3 progenies, each F_2 plant being the parent of an F_3 progeny row. The kernels were spaced 3 to 4 inches in rows 1 foot apart. From 30 to 50 plants were usually in each row.

Parental varieties were sown alternately after each tenth progeny row, making a total of 23 rows of Federation and 22 rows of Sevier 59. The same manner of seeding and spacing was observed for the parental rows as was done with the progenies.

Each F_3 progeny and parent row was harvested at maturity by carefully pulling each plant. During the fall and winter each plant was so studied in the laboratory that the data from each row could be easily traced to its proper progeny.

EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

Mean spike density and coefficients of variability for each F_3 progeny were calculated and used to aid in classifying spike-density groups and for correlation studies. Awn classes were determined by inspection, although the mean length of awns and coefficient of variability were calculated from length measurements. A definite figure was obtained for awn length and spike density for each plant in an F_3 progeny. A mean, a standard deviation, and a coefficient of variability were obtained for these two characters. Comparative studies were then made and the method of segregation observed wherever it could be established that segregation took place. The means obtained in this study were used in correlation studies as more accurate than the measurements of the individual F_2 plants.

INHERITANCE OF INDIVIDUAL CHARACTERS

A study of the inheritance was made for the plant characters of awn classes and spike density.

Awn classes.—Awn behavior in this cross was rather complicated. The Sevier 59 parent is homozygous for awn class 4, while Federation is homozygous for awn class 1. Nine genotypes were noted in the F_3 of which four were true-breeding and five were segregating groups. When the results were compared to the possible 1:2:2:4:1:2:1:2:1 ratio, X^2 was large and P = .0003, which is a very poor fit. The two parental types (awn classes 1 and 4) occurred more frequently than the other true-breeding classes (2 and 3), as follows:

Number of F_3 families breeding true for	
Awns 1	51
Awns 2	20
Awns 3	18
Awns 4	40

Such a segregation suggests linkage, as it had done some years before in the original cross of these two varieties. Various degrees of linkage were examined on the basis of a two-factor difference with gametes produced in various proportions. The best fit was obtained with gametes in proportions of 1.6:1:1:1.6.

Awns were previously designated as:

Awns 4 = AATT
Awns 3 = AAtt
Awns 2 = aaTT
Awns 1 = aatt

With independent assortment of the gametes an equal number of the true-breeding classes should be produced. The numbers obtained were very different. Table 1 shows the theoretical number and sort of both gametes and zygotic combinations resulting in F_2 on the gametic ratio of 1.6:1:1:1.6.

TABLE 1.—*Theoretical number and sort of gametes produced by F_1 plants and theoretical number and sort of zygotic combinations resulting in F_2.*

	1.6 AT	1.0 At	1.0 aT	1.6 at
1.6 AT	2.56 AATT	1.6 AATt	1.6 AaTT	2.56 AaTt
1.0 At	1.6 AATt	1.0 AAtt	1.0 AaTt	1.6 Aatt
1.0 aT	1.6 AaTT	1.0 AaTt	1.0 AaTT	1.6 aaTT
1.6 at	2.56 AaTt	1.6 Aatt	1.6 aaTt	2.56 aatt

Summary of theoretical zygotic combinations in F_2 together with their F_3 breeding behavior.

(1) AATT	2.56	True for awns 4	(6) Aatt	3.20	Segregate for awns 1, 2, and 3
(2) AATt	3.20	Segregate for awns 3 and 4			
(3) AaTT	3.20	Segregate for awns 2, 3, and 4	(7) aaTT	1.00	True for awns 2
(4) AaTt	7.12	Segregate for awns 1, 2, 3, and 4	(8) aaTt	3.20	Segregate for awns 1 and 2
(5) AAtt	1.00	True for awns 3	(9) aatt	2.56	True for awns 1
				27.04	

When gametes are produced in this proportion, there is 38.4% crossing over. On this basis, Table 2 gives for the goodness of fit the value for X^2 as 3.174 and P = .9189, which is an unusually good fit.

A similar condition was previously formed in an independent cross made at the Utah Station in which the gametic ratio of 1.8:1:1:1.8, making 35% crossing over, gave the best explanation of the results obtained. The same ratio was tried in this case, and although a good fit resulted, the 1.6:1:1:1.6 ratio gave the best fit in the series (Table 3).

TABLE 2.—*Goodness of fit of 9 F_1 genotypes for the various awn classes on the basis of linkage with gametes in the ratio of 1.6: 1:1:1.6.*

Genotype	Observed value (O)	Calculated value (c)	O-C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
AATT	40	42.4	2.4	5.76	.136
AATt	52	53.0	1.0	1.00	.019
AaTT	50	53.0	3.0	9.00	.170
AaTt	115	118.0	3.0	9.00	.073
AAtt	18	16.6	1.4	1.96	125
Aatt	51	53.0	2.0	4.00	.079
aaTt	51	53.0	2.0	4.00	.723
aaTT	20	16.6	3.4	11.56	.079
aatt	51	42.4	8.6	73.96	1.760
			$X^2=3.174$	$P=.9189$	3.174

TABLE 3.—*The X^2 and P values for various gametic ratios studied.*

Gametic ratio	X^2 values	P values
1.8:1:1:1.8	4.427	0.8070
1.7:1:1:1.7	3.654	0.8374
1.6:1:1:1.6	3.174	0.9189
1.5:1:1:1.5	3.610	0.8304

The results of the Sevier 59 x Federation cross indicate two factors affecting awn inheritance, both of which are located in the same chromosome with about 38% crossing over. Crossing the two intermediate awn types and back crossing on one or both parents would give a check on the correctness of this hypothesis.

Spike density.—Sevier 59 used as one of the parents in this cross has a spike of intermediate density resembling the F_1 ordinarily obtained when a lax and club wheat are crossed. The spike density of the parents was rather nearly alike, yet no overlapping was observed, as seen in Fig. 2 and Table 4. From the tables presented a clear-cut segregation is evident in which three spike density groups were obtained. A condition of true-breeding dense and true-breeding lax progenies was found when studied by the goodness of fit on the basis of a single-factor difference and a 1:2:1 ratio. Table 5 shows calculated and observed ratios for spike density classes in which $X^2 = 1.185$ and $P = .5826$, which is a good fit. As determined by the coefficient of variability, 111 progenies were homozygous for dense spikes; 234 were heterozygous; and 103 homozygous for lax spikes. A normal one-factor difference, however, fails to account for the unusual situation found by examining the homozygous dense progenies. The cross produces true-breeding dense and lax progenies, transgressive far beyond the limits of either parent. The Sevier parent, moreover, was recovered in only a few of the homozygous lax progenies.

TABLE 4.—*Frequency distribution of the Sevier 59 and Federation parents and of F_3 progenies arranged into classes according to the mean spike density and according to the coefficients of variability (C. V.) classes of the individual rows and of the F_3 progenies.**

	Spike density classes (millimeters)																				Total	C. V. classes	Total No. individuals
	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72			
Sevier 59	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	2	22
	—	—	—	—	—	—	—	1	3	—	—	—	—	—	—	—	—	—	—	—	4	5	
	—	—	—	—	—	—	—	3	2	3	—	—	—	—	—	—	—	—	—	—	8	8	
	—	—	—	—	—	—	—	4	2	3	—	—	—	—	—	—	—	—	—	—	9	11	
Federation	—	—	—	—	—	—	—	—	—	—	—	—	5	2	2	—	—	—	—	—	9	5	23
	—	—	—	—	—	—	—	—	—	—	—	2	4	5	1	—	—	—	—	—	12	8	
	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	2	11	
F_3 Progenies	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	2	448
	—	—	1	1	—	—	—	—	—	—	—	—	—	2	5	15	16	4	—	—	44	5	
	—	2	10	13	3	2	1	—	—	—	—	—	1	4	7	18	19	7	3	—	90	8	
	—	—	9	33	3	2	—	2	—	—	—	—	—	—	—	—	—	—	—	—	49	11	
	—	—	4	9	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17	14	
	—	—	—	1	—	—	—	1	1	1	—	—	—	—	—	—	—	—	—	—	4	17	
	—	—	—	1	—	—	—	1	1	1	—	—	1	—	—	—	—	—	—	—	5	20	
	—	—	—	1	—	—	1	3	5	3	—	2	1	1	—	—	—	—	—	—	17	23	
	—	—	—	—	1	—	—	6	8	10	5	—	1	—	—	—	—	—	—	—	31	26	
	—	—	—	—	—	1	3	8	10	13	5	3	1	—	—	—	—	—	—	—	44	29	
	—	—	—	—	—	2	6	7	13	12	6	3	—	—	—	—	—	—	—	—	49	32	
	—	—	—	—	1	1	5	9	7	9	2	—	—	—	—	—	—	—	—	—	34	35	
	—	—	—	—	—	2	3	10	8	3	2	1	—	—	—	—	—	—	—	—	29	38	
	—	—	—	—	—	1	6	4	2	—	1	—	—	—	—	—	—	—	—	—	14	41	
	—	—	—	—	—	2	3	4	2	—	1	—	—	—	—	—	—	—	—	—	12	44	
	—	—	—	—	1	—	3	2	1	—	—	—	—	—	—	—	—	—	—	—	7	47	
	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	50	

*Family 18a–3; grown at Logan, Utah.

Table 4 and Fig. 1 present this distribution of the various F_3 progenies and of the parent rows for spike density. A theory has been sought, but not found, which will explain the peculiar inheritance of spike density found in this and in similar crosses involving the Sevier parent.

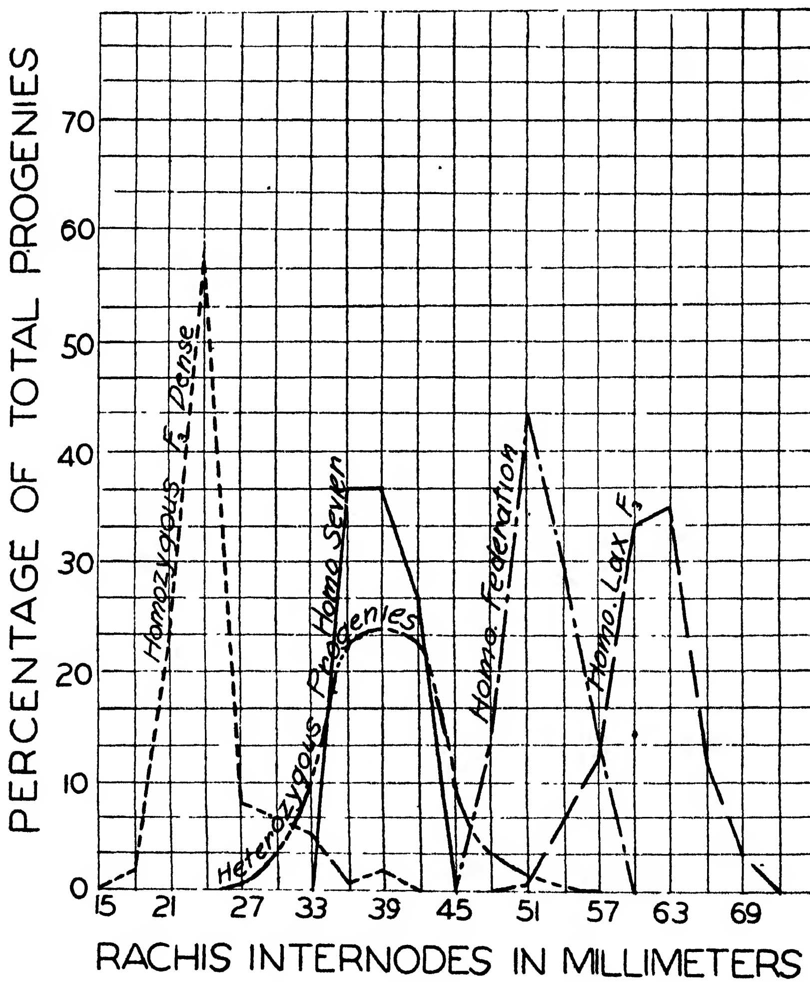

FIG. 2.—Spike density curves of the Sevier 59 and the Federation parents and of the F_3 progenies obtained from the cross. It is to be noted that a considerable number of progenies were true-breeding for more lax spikes than the more lax parent and that all the true-breeding dense progenies, except two or three, are more dense than the more dense parent. True *compactum* forms were obtained from the cross of these two *vulgare* parents.

TABLE 5.—*Goodness of fit for spike-density classes on a 1:2:1 ratio.**

Class	Calculated value (c)	Observed (O)	O-C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
Homozygous dense	112	111	1	1	.0090
Heterozygous.....	224	234	10	100	.4440
Homozygous lax...	112	103	9	81	.7232
			P=.5826	$X^2=1.1852$	

*Family 18a-3; grown at Logan, Utah.

Correlation studies.—Correlation studies were made between length of awns and spike density. In a previous cross at the Utah Station a Kanred x Sevier cross revealed a high correlation between awn length and spike density.[6] A similar situation was discovered in this cross of Sevier 59 x Federation. With all the awn classes grouped together, a correlation, represented by r = + .5664 ± .0258, was obtained. Only 316 of the 448 progenies were measured for awn length, those omitted being of the shorter-awn groups. For this reason the longer-awned classes were studied separately as all of them were measured. The 40 true-breeding awn class 4 progenies gave a correlation coefficient (r) of + .677 ± .0578, which is 11 times the probable error. When the true-breeding awn class 3 and the group segregating for awns 3 and awns 4 were included with awns class 4, the correlation coefficient (r) was + .479 ± .05, which is 9.6 times its probable error.

Summary of Sevier x Federation cross.—Awn inheritance was found to be rather complicated, consisting of nine genotypes in the F_3. A suggestion of linkage requiring 38.4% crossing over to explain the results was also obtained. With no linkage considered P = .0003, while on the basis of a gametic ratio of 1.6:1:1:1.6 which gives 38.4% crossing over P = .9189, which is an exceptionally good fit. The homozygous awn classes resembling the awn conditions of Sevier 59 and of Federation appeared more frequently by far than the other homozygous awn classes.

Spike density inheritance was also of unusual behavior. The homozygous F_3 progenies fell far beyond the limits of the parental strains in the direction of the dense or club type. The density of the Sevier 59 parent was recovered in only two or three true-breeding progenies. However, a 1:2:1 ratio was suggested by the 111 homozygous dense progenies, 234 heterozygous, and 103 homozygous lax progenies. When studied in a goodness-of-fit table for the expected

[6]STEWART, G. Correlated inheritance in Kanred x Sevier varieties of wheat. Jour. Agr. Res., 36: 873–896. 1928.

ratios on a one-factor difference, $X^2 = 1.185$ and $P = .5826$. The coefficient of variability method of classification gave clear-cut segregating classes in this cross for the character of spike density.

Correlation studies were made between spike density and awn length. This showed a high correlation coefficient, r, which was $+ .566 \pm .026$ when all the progenies measured were considered. With only the 40 fully-awned progenies, the correlation coefficient was $+ .677 \pm .0578$ and when awn class 3, awn class 4, and the group segregating for awns 3 and 4 were grouped together, $r = + .479 \pm .05$.

CROSS BETWEEN SEGREGATES OF INTERMEDIATE AWN TYPE

Now, if the awn-group classification is correct, the crossing of the two segregates of intermediate awn types, awn class 2 and awn class 3, should yield all four classes. Furthermore, if the linkage indication be correct, this cross between the two intermediates should show linkage between awn groups 2 and 3 and a repulsion between awn groups 1 and 4.

A true-breeding segregate belonging to awn group 2 (pedigree 5–51–1) was crossed with a true-breeding segregate belonging to awn group 3 (pedigree 5–69–3). The F_1 plants, several in number, all resembled the F_1 obtained from the parental cross Sevier (awn group 4) x Federation (awn group 1). A productive, vigorous F_1 plant was chosen and the next spring its kernels, more than 400 in number, were spaced 3 or 4 inches in rows 1 foot apart. A large F_2 generation of 399 plants was thus secured. One spike from each F_2 plant was threshed and the kernels from each placed in a separate envelope and the following spring used to seed the F_3 generation. The kernels were seeded 2 or 3 inches apart, one progeny to a row with a few parental rows interspersed for checks. (See Figs. 3 and 4.)

At harvest time, the F_3 progenies were pulled and classified by the writer and a graduate-student assistant working together. Spike-density studies were not made in this cross, though this could have been done as 5–51–1 had a compact spike and 5–69–3 a lax one. The field used was rather severely infested with green foxtail (*Setaria viridis*), due probably to contaminated irrigation water. The progenies had to be weeded in order to permit proper development of the plants. At harvest, 12 progeny rows contained less than 10 plants each and 2 contained no plants. It was thought wisdom to discard these 12 progenies as having too few plants to permit proper genetic classification; however, they could have been included without any material influence on the data.

Following the factorial designation previously used, parents AAbb x aaBB, F_1 AaBb, F_2 segregation, and F_3 breeding behavior gave the results shown in Table 6.

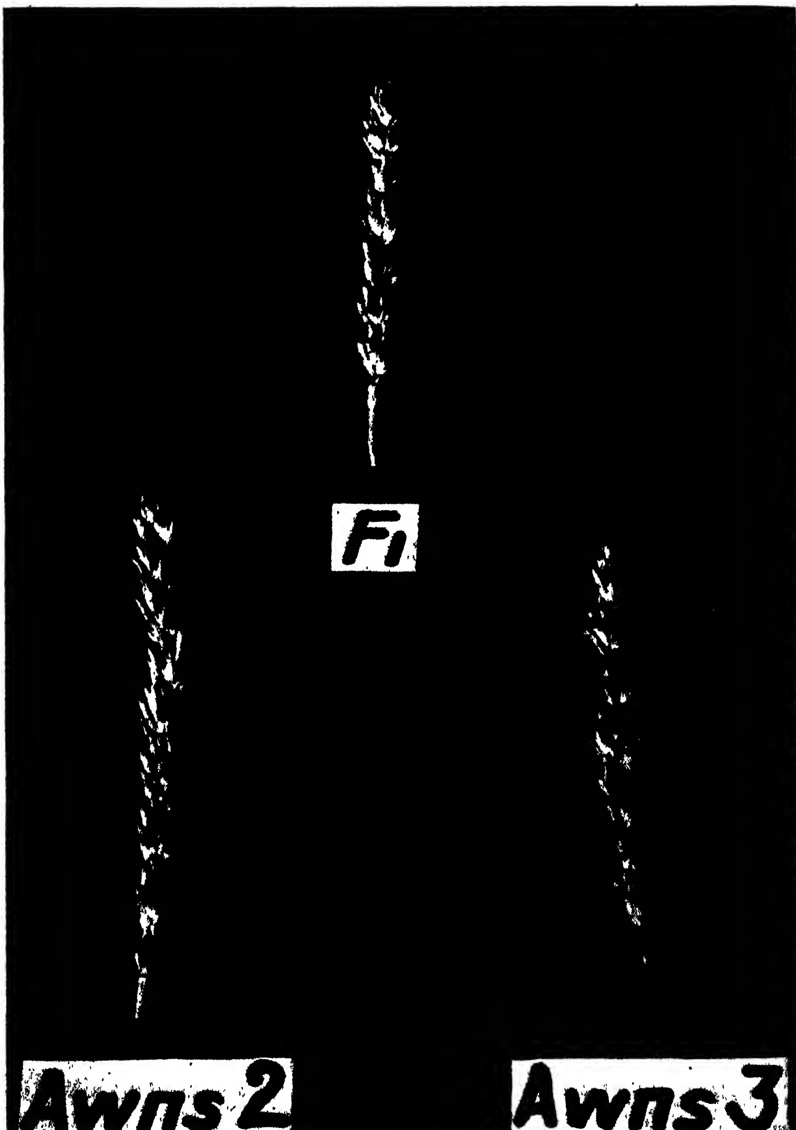

FIG. 3.—*Below:* The two intermediate awn classes (awns 2 and 3) used as parents, showing the development of awns on different parts of the spike. These should be compared with Figs. 1 and 4. *Above:* The F_1 from the two parental forms. Fig. 4 shows the true-breeding forms obtained from this cross.

TABLE 6.—*F_2 genotypes and F_3 breeding behavior of progenies from a cross of 5–51–1 (awns 2) and 5–69–3 (awns 3).*

Class No.	F_2 Genotypes	F_3 breeding behavior for awns
1	1 AABB	True-breeding 4
2	2 AABb	Segregating 3, 4
3	2 AaBB	Segregating 2, 3, 4
4	4 AaBb	Segregating 1, 2, 3, 4
5	1 aaBB	True-breeding 3
6	2 aaBb	Segregating 1, 2, 3
7	1 AAbb	True-breeding 2
8	2 Aabb	Segregating 1, 2
9	1 aabb	True-breeding 1

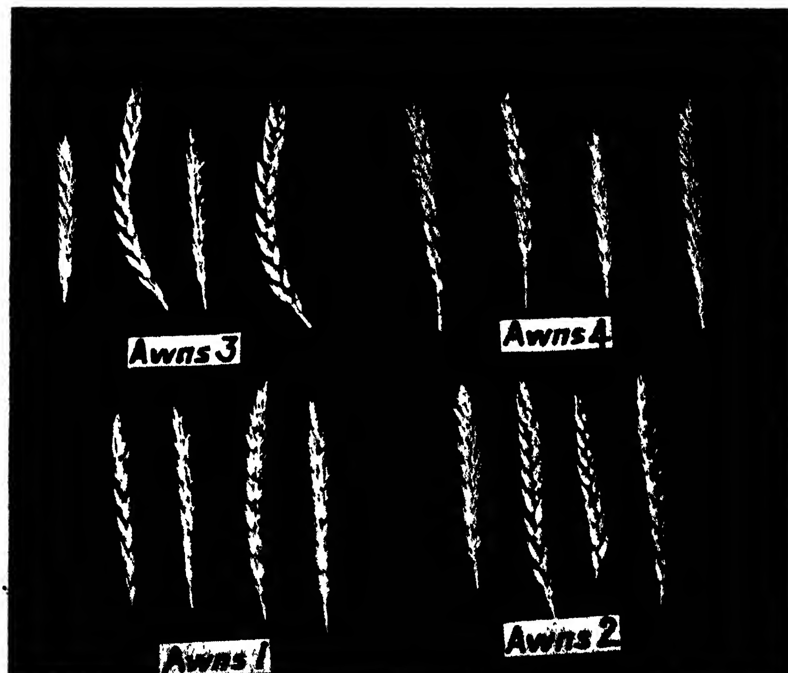

FIG. 4.—The four awn classes obtained from crossing the two intermediates shown in Fig. 3. By comparing these with Fig. 1, it may be seen that the classes obtained are the same as in the original cross when awns 1 and awns 4 were the parental forms. True-breeding progenies in each awn class were secured. The awn classes originally established are probably the correct ones for this cross

After the 12 progenies with less than 10 plants were discarded, there were 385 progenies regarded as good genetic material. These gave the segregation shown in Table 7.

TABLE 7.—*Number of F_3 progenies belonging to F_2 genotype, as indicated by the F_3 breeding behavior.*

Class No.	Number of progenies	F_3 breeding behavior
1	27	True-breeding for 4
2	54	Segregating 3, 4
3	53	Segregating 2, 3, 4
4	92	Segregating 1, 2, 3, 4
5	20	True-breeding 3
6	45	Segregating 1, 2, 3
7	26	True-breeding 2
8	49	Segregating 1, 2
9	19	True-breeding 1
	385	

On the basis of independent assortment the closeness of fit between the expected and the obtained data are studied in Table 8.

TABLE 8.—*Closeness of fit between expected and observed data, ratio independent assortment, 1:2:2:4:1:2:1:2:1, 5-51-1 (awns 2) x 5-69-3 (awns 3); grown at Logan, Utah.*

Class No.	Observed (O)	Calculated (c)	O-C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
1	27	24.0625	2.9375	8.6289	.3586
2	54	48.1250	5.8750	34.5156	.7172
3	53	48.1250	4.8750	23.7656	.4939
4	92	96.2500	4.2500	18.0625	.1877
5	20	24.0625	4.0625	16.5039	.6859
6	45	48.1250	3.1250	9.7656	.2030
7	26	24.0625	1 9375	3.7529	.1560
8	49	48.1250	0.8750	0.7656	.0160
9	19	24.0625	5.0625	25.6289	1.0651
			P = .8661	$X^2 = 3.8834$	

The 12 discarded progenies distributed themselves as shown in Table 9.

TABLE 9.—*Distribution of 12 progenies having less than 10 plants each.*

Pedigree No.	Number of plants in awn group			
	1	2	3	4
82	5	3	–	–
127	–	–	2	–
174	1	2	–	–
182	–	2	–	1
186	–	3	–	–
221	2	3	–	–
223	2	6	1	–
306	–	–	6	–
312	–	–	–	4
313	–	–	1	–
392	–	–	1	4
395	–	–	–	5

These 12 rows group themselves as follows:

Class No.	Number of progenies
1	2
2	1
3	1
4	0
5	2
6	2
7	2
8	2
9	0

These numbers, when added to their respective classes, give a closeness of fit of .7760, which is somewhat lower than the one reported but not enough so to alter the conclusions in any way.

On the basis of linkage with gametes in the ratio of 1:1.6:1.6:1 which gave the highest figure for closeness of fit in the original cross repeated, the expected ratio is shown in Table 1 to be

Class No.	Expected
1	1.00
2	3.20
3	3.20
4	7.12
5	2.56
6	3.20
7	2.56
8	3.20
9	1.00
	27.04

A closeness-of-fit study on this basis shows $X^2 = 27.18$ and P = less than 0.000001, which indicates no evidence of linkage.

This cross bears out in a striking way the classification of awns, but throws doubt on the occurrence of linkage. It should be observed as valuable evidence that segregates from a cross of the two intermediate classes, 2 and 3, re-assembled the factors for awns and restored the two parental awn classes, 1 and 4, without evidence of factor modification or alteration. This is strong evidence that proper awn classes were established in the original cross and in its repetition.

BACK CROSSES BETWEEN SEGREGATES AND THE FEDERATION PARENT

A third cross was made between Federation (awn class 1) and a segregate true-breeding for awn class 3 (pedigree 5–69–3). The F_1 expression for awns was a weak awn class 2. Just less than 400 kernels were obtained from the most vigorous F_1 plant. These

were seeded the following spring to grow F_2 plants, spaced 3 or 4 inches in rows a foot apart. A single head from each F_2 plant furnished kernels for seeding an F_3 progeny the next year. In all, there were 378 F_3 progenies seeded; one, however, produced no plants. At the harvest of the F_3 progenies, these plants were classified by two reliable assistants. The data obtained were as follows:

	Number of progenies
True-breeding for awns 1	86
True-breeding for awns 3	89
Segregating for awns 1, 2, 3	202
Total	377

These data suggest a 1:2:1 ratio and the closeness of fit on that basis is shown in Table 10.

TABLE 10.—*Closeness of fit between observed and expected number of progenies on basis of 1:2:1, ratio Federation (awns 1) x 5–69–3 (awns).**

F_3	Observed (O)	Calculated (c)	O-C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
Awns 1	86	94.25	8.25	68.0625	.7221
Awns 1, 2, 3	202	188.50	13.50	182.2500	.9720
Awns 3	89	94.25	5.25	27.5625	.2924
			P = .3711	X^2 = 1.9865	

*Family 86a (Federation x 5–51–1); grown at Logan, Utah.

Here is good evidence of a one-factor difference between Federation (awns 1) and segregate 5–69–3 (awns 3). Not only is the probability of .37 satisfactory, but there was not a single progeny which even approached homozygosity for anything other than awns 1 and awns 3. Neither was there segregation beyond the expected range.

A fourth cross was between Federation (awns 1) and segregate 5–51–1, true-breeding for awns 2. The F_1 plant had an awn expression about half way between awns 1 and a good expression for awns 2. A vigorous F_1 plant furnished more than 400 kernels, all of which were seeded, properly spaced, to grow F_2 plants, of which 412 were obtained. Grain from each of these seeded an F_3 progeny row in which the plants were spaced 2 or 3 inches apart. As two progenies produced only one plant each, they were discarded. At harvest time, the plants in each F_3 progeny were classified for awns and measured for spike density. The awn data were as follows:

	Number of progenies
True-breeding for awns 1	93
True-breeding for awns 2	111
Segregating for awns 1, 2	206
Total	410

Since these data suggest a 1:2:1 ratio, they were studied in Table 11 on this basis for closeness of fit.

TABLE 11.—*Closeness of fit between observed and calculated number of progenies on a basis of 1:2:1, Federation (awns 1) x 5-51-1 (awns 2).*

F_3 behavior	Observed (O)	Calculated (C)	O-C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
Awns 1....	93	102.5	9.5	90.25	.8804
Awns 1, 2..	204	205.0	1.0	1.00	.0048
Awns 2..	111	102.5	8.5	72.25	.7049
			P=.4657	X^2=1.5901	

The evidence in this case is also strong that there is a one-factor difference between Federation (awns 1) and segregate 5-51-1 (awns 2), which is further evidence that the awn classes originally made were correct. The probability of .47 indicates a satisfactory fit. Moreover, there was no suggestion of any sort of true-breeding progeny other than awns 1 and awns 2. However, there were two aberrant progeny rows, one with a single long-awned (awns 4) plant and one progeny with five awns 3 plants, and six awns 4 plants along with 18 awns 2 plants. The occurrence of these two lone rows suggests not transgressive segregation but rather a mechanical mixture of one kernel in one case and a chance hybrid in the other.

The spike densities were studied by the coefficient of variation (C. V.) method previously used. They are given in Table 12 where it is shown that the F_3 progenies are grouped into three distinct classes. There is doubt about only 1 progeny out of 410. With segregation thus clearly defined, the approach to a 1:2:1 ratio is manifest. Judged by the table, both parents were fully recovered, with an intermediate segregating group.

In this family there were 104 progenies true-breeding for dense spikes and 97 true-breeding for lax spikes, leaving 209 heterozygous. Here is good evidence that there is a one-factor difference for spike density between the parents, which corroborates previously reported data. Closeness of fit is shown in Table 13. Since X^2 is less than 1.0, P is very high.

SUMMARY

A cross studied at the Utah Station several years ago between the wheat varieties Sevier and Federation indicated two factors for awns with a suggestion of linkage and a peculiar spike density inheritance. To test these segregations the cross was repeated.

Spike density behavior was again found to be similarly peculiar in that wide transgressive segregation was found, some progenies having

TABLE 12.—*Frequency distribution of the Federation and 5–51 1 parents and of F_3 progenies, arranged into classes according to the mean spike density and according to coefficients of variability (C. V.) classes of the individual parental rows and of F_3 progenies.**

	Spike density classes (millimeters)																	Total	C. V. classes	Total number of individuals
	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63			
Federation . .	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	3	5	6
	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	3	8	
5–51–1	—	2	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	8	8
	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	11	
	—	2	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	4	2	
	—	25	27	2	—	—	—	—	—	—	—	9	22	20	5	—	1	111	5	
	—	13	25	—	—	—	—	—	—	—	1	5	12	12	4	1	—	73	8	
	—	—	3	—	1	—	—	—	—	—	—	1	—	1	1	—	—	7	11	
	1	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	3	14	
	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	2	17	
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	20	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	23	
F_3 Progenies.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	26	410
	—	—	—	1	1	1	2	—	—	—	—	—	—	—	—	—	—	5	29	
	—	—	1	1	2	3	4	—	—	—	—	1	—	—	—	—	—	12	32	
	—	—	—	—	11	7	4	5	2	—	—	—	—	—	—	—	—	29	35	
	—	—	—	—	11	7	8	5	1	1	—	—	—	—	—	—	—	33	38	
	—	—	—	1	12	20	21	9	3	—	—	—	—	—	—	—	—	66	41	
	—	—	—	—	2	19	12	2	—	2	—	—	—	—	—	—	—	37	44	
	—	—	—	1	2	11	9	—	—	—	—	—	—	—	—	—	—	23	47	
	—	—	—	—	1	1	1	—	—	—	—	—	—	—	—	—	—	3	50	
	—	—	—	—	11	—	—	—	—	—	—	—	—	—	—	—	—	1	53	

*Family 86a; grown at Logan, Utah.

TABLE 13.—*Closeness of fit for spike density between observed and calculated data on basis of 1:2:1 ratio.**

Breeding behavior	Observed	Calculated	O-C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
True-breeding dense	104	102.5	1.5	2.25	.0220
Heterozygous......	209	205.0	4.0	16.00	.0781
True-breeding lax...	97	102.5	5.5	30.25	.2951
			P = Very high	$X^2 = .3932$	

*Family 86a; Federation (lax spikes) x 5–51–1 (dense spike); grown at Logan, Utah.

spikes more dense than either parent and other progenies with spikes more lax than either parent. Neither parent is a *T compactum* and yet about 25% of the progenies are distinctly *compactum*. The parental spike densities were recovered in only a few progenies, fewer for the more dense parent, Sevier, than for the more lax parent, Federation.

In awn behavior there were found four true-breeding awn classes, one like each parent and two intermediates. The suggestion of linkage was again found as it had been in the original cross studied in 1925, which data were corroborated almost exactly by the repeated cross.

One parent Federation was awnless and the other, Sevier, was fully awned. Two intermediate awn classes, designated as awns 2 and 3, were obtained. According to the early study; these were thought to represent different intermediate types each genetically one factor removed from either parent, Federation lacking both and Sevier containing both factors. If these conclusions are correct, a cross of the two intermediate forms should re-assemble the factors and restore the parents. When this cross was made and the F_2 plants and F_3 progenies studied, the grandparental types (awnless and fully awned) were restored along with the intermediates. The only difference noted in crossing awnless x fully awned and in crossing the two intermediates was that there was no suggestion of linkage in the second case. It was clear-cut that awn classes 2 and 3 were re-assembled into awn class 1 (awnless) and awn class 4 (fully awned).

A back cross of the awnless parent (Federation) on each of the intermediate awn classes 2 and 3 should reveal if there was really a one-factor difference. When the two backcrosses were studied, there was found to be a single-factor difference between the awnless parent and each of the intermediates, as is shown by the fact that P = .37 for one backcross and P = .46 for the other.

It was also clear that awn class 2 was different from awn class 3 as only progenies true-breeding for awn class 1 and 2 were found in

the backcross of Federation on awn class 2. On the other hand, progenies true-breeding for only awn classes 1 and 3 were found in the backcross of Federation on awn class 3.

These two backcrosses establish the correctness of the original awn classes set up in 1925 when the original cross was studied. Fully true-breeding progenies in all four awn classes also bear out the original classification.

Incidentally, the data presented in these crosses and backcrosses furnish some presumptive evidence that it is the awnless wheat which lacks the factors, i. e., is recessive. However, in a strictly intermediate dominance, it is really difficult, and not highly essential to breeding work, to prove whether the awnless condition is recessive or dominant.

One of the two backcrosses permitted a test to see if there was a one-factor difference between the spike density of the lax parent and a dense-spiked segregate. There was found to be a one-factor difference, and as $X^2 = .39$, P is extremely high.

PARENT-PROGENY CORRELATIONS IN CORN[1]

J. FRED O'KELLY and W. W. HULL[2]

The desire to find easily recognizable physical characters in corn which are associated with yield and which can be used as criteria in selection has prompted extensive experimentation. Many data have been secured and published concerning the correlation of ear characters with each other and with yield. The studies were made in connection with several systems of breeding, but in the main they concern ear-to-row methods. The results are somewhat conflicting, but, on the whole, have been disappointing in that no such characters have been found

Prior to 1925, the Mississippi Agricultural Experiment Station began a system of plant-to-row corn breeding which is described fully below. Like many other systems, it uses the progeny yield to determine what shall be retained and what discarded, but it differs from others in certain respects, as will be observed from the description. The operation of this system offered an opportunity to collect additional correlation data between characters of the parent

[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication March 24, 1932.

[2]Agronomist and Plant Breeder and Assistant Plant Breeder, respectively.

plant and its progeny under conditions somewhat different from those under which many other data have been collected and, since other results have failed to show any close relation between parent and progeny, it seemed worthwhile to collect such data; for, regardless of experimental findings, the grain of the parent must contain, however completely masked they may be, those factors which determine whether the progeny shall be a high, average, or low producer. Only these correlations are reported here. The merits of the system of breeding are to be reported later.

The primary purpose of this study is to show, under the conditions of a particular breeding method, the degree to which the relative yield of the mother plant indicates the relative yield of the progeny. Of secondary importance is the degree of inheritance of grain percentage. Only these two characters are included in this study. It has been possible to derive coefficients of correlation for each of these characters in the parent with the other in the progeny, and these values are reported in order to add to the evidence secured by other investigators. The correlations are in all cases between the parent and its progeny and include yield with yield, grain percentage with grain percentage, yield with grain percentage, and grain percentage with yield.

The published data on corn correlations have been reviewed by a number of writers,[3] and it is not deemed necessary to include a detailed review in this report. Some workers have confined their studies to one generation. The evidence from such studies indicates that correlations within a generation are physiological or, if factorial, are so slight as to be of no practical value. Other workers have reported correlation studies which consider both the parent and progeny generations, but which concern plant characters not being considered here. Some of these characters have seemed to be slightly related to yield, but not to a degree sufficient to justify selection from among good seed ears on the basis of such characters as a method of corn breeding.

As already mentioned, the primary purpose of the writers was to study the correlation between parent and progeny yield. Other workers have determined the relation between seed ear weight and progeny yield. If it were known that each ear used by these workers was the total yield of the mother plant, the correlations they found

[3]KIESSELBACH, T. A. Ear type selection and yield of dent corn. Jour. Amer. Soc. Agron., 14: 27–48. 1912.

RICHEY, F. D. The experimental basis for the present status of corn breeding. Jour. Amer. Soc. Agron., 14: 1–17. 1912.

would be directly comparable to those in this study. This is not definitely known to be the case, but the fact that most of the work was done in the northern states where one-ear types prevail would indicate that seed ear weights as reported closely approximate total plant yields. The data indicate a tendency for the heavier ears to produce the larger yields, but the tendency is so slight that seed ear weight cannot be looked upon as a reliable index of progeny yield.

A number of investigations concerning the relation of grain percentage to yield have been reported. While the results are somewhat conflicting, they are in agreement that if correlation exists at all it is very weak The majority of the studies indicates a slight tendency for high progeny yields to be associated with relatively low percentage of grain.

In so far as the writers are able to determine, no studies have been reported of the relation between parent yield and progeny grain percentage or between the grain percentage of the parent and that of the progeny

MATERIALS AND METHODS

The correlation studies reported here were made in connection with the regular breeding work of the Mississippi Experiment Station. A description of this system seems advisable.

The station is using the plant-to-row method with certain modifications To begin the project, plant-to-row plats are carried out in the usual way, each plat being replicated. The yield of seed corn is recorded for each plat, and a sample is taken from which the grain percentage is determined. From these records the yield of grain is calculated. On the basis of grain yield, the best progenies are selected, prerequisites being that a progeny must yield above the average of all and must yield well in comparison with adjacent rows in both series of plats. Seed from progeny rows so selected are massed together and stored. Contemporary with this process of selecting the highest yielding progeny rows, individual plant selections are made and records taken similar to those in the case of progenies. On the basis of these records, the best selections are saved and given a number This completes the first year's work

The following year, these selections are planted one to a row in sequence, but after every four such rows, two rows are planted with the seed saved from the best progenies of the year before. The planting order, then, is four progeny rows, two rows from massed, previously tested and selected seed, four more progeny rows, etc. All progenies are detasseled and thus made to get their pollen from

plants whose ♀ parents and ♂ grandparents are known to have produced high yields. Records are taken and the best progenies chosen just as described for the first year. Since seed so selected is to furnish pollen the next year, it is designated by the male symbol ♂. The plan for all succeeding years is identical with that described for the second year.

In making individual plant selections, care is exercised to consider only those plants which have approximately equal environmental opportunity, such as space, soil fertility, etc. Beginning with the second year, these selections are made from among plants grown from the seed designated ♂.

Regardless of the fact that every progeny is cross pollinated, it will be seen from the above that this system involves a certain amount of inbreeding. Suppose that each year there are 100 progenies and that each year 20 of these are used as the male material from which plant selections are to be obtained. Each year, then, the 100 selections to be used for growing progenies come from the second generation of 20 plants. Likewise, all the pollen that is disseminated over the field traces back to 20 plants and is only two generations removed from them. As the process continues from year to year, the range of selection material is constantly narrowed. In order to reduce the intensity of inbreeding, plant selections are made from a separate field of corn planted with ♂ seed and not from those male rows within the plant-to-row plats. In the latter case, plant selections would likely have much the same genetic constitution as progeny rows selected for next year's male material, whereas, under the system used, this possibility is more remote. Because of this fact and the fact that all progenies are detasseled, there is probably less inbreeding accomplished by this system than by most plant-to-row methods.

The Mississippi Station is working on four varieties of corn by this breeding method, and the correlation studies being reported were made with these varieties, which are Mosby, Cocke's Prolific, Laguna, and Goliad.

The number of individuals of each variety for the different years is given in Table 1. The year mentioned in the table refers to the one in which the progeny was grown.

YIELD WITH YIELD

For use in calculating coefficients of correlation, actual grain yield in the case of both parents and progenies has been converted from pounds to percentage of the average. Table 2 gives the coefficients for parent yield with progeny yield.

TABLE 1.—*Number of progenies grown.*

Year	Mosby	Cocke's Prolific	Laguna	Goliad
1925	—	82	—	—
1926	152	131	—	99
1927	108	110	79	111
1928	108	100	112	104
1929	118	95	103	107
1930	122	100	—	110

TABLE 2.—*Correlation coefficients for yield with yield.*

Year	Mosby	Cocke's Prolific	Laguna	Goliad
1925	—	—.2249±.0707	—	—
1926	.0941±.0542	.1387±.0578	—	2294±.0642
1927	.2165±.0619	—.0346±.0642	.075 ±.0755	.2012±.0614
1928	.0178±.0649	.0545±.0672	— 0297±.0637	.0793±.0657
1929	.1871±.0599	.0659±.0689	.2025±.0637	.1683±.0634
1930	—0122±.0611	.1497±.0659	—	.2636±.0598

It will be seen from Table 2 that perhaps none of the coefficients are statistically significant However, there are only 4 out of 19 that are negative and only 1 of these is in the first decimal. From this viewpoint, it would seem that there is a slight tendency for high-yielding parents to produce high-yielding progenies However, from the practical standpoint, a breeder cannot, on the basis of these results, place much confidence in the yield of a plant as an index to its genetic constitution so far as factors for yield are concerned. To try to explain why this is true would be more or less futile, but it would seem that it is due to the fact that environmental variation almost completely obscures the inherent producing capacity of an individual plant. Whether or not this capacity is more completely expressed in the progeny has not been proved, but it would seem that with a large number of plants at work, the progeny yield should be a better index of the inherent yielding capacity than is the parent yield.

GRAIN PERCENTAGE WITH GRAIN PERCENTAGE

Wherever grain percentage is involved in these correlations, the actual percentage of grain is used and not the percentage of the average of all parents and progenies as was the case with yield. The coefficients of correlation for parent grain percentage with progeny grain percentage are given in Table 3.

Examination of Table 3 shows that the grain percentage of the parent is strongly correlated with the grain percentage of the progeny. The coefficients range from .5267 ± .0441 to .8066 ± .0237 and are in

TABLE 3.—*Correlation coefficients for grain percentage with grain percentage.*

Year	Mosby	Cocke's Prolific	Laguna	Goliad
1925	———	.6347±.0445	———	———
1926	.5949±.0353	.6449±.0344	———	.8066±.0237
1927	.6415±.0382	.7239±.0306	.5917±.0493	.6108±.0401
1928	.6800±.0349	.6978±.0346	.7146±.0312	6665±.0368
1929	.6861±.0329	.6911±.0362	.7365±.0304	.7432±.0292
1930	.5267±.0441	.5633±.0460	———	.7220±.0308

every case many times the probable error. This suggests to the breeder that he can make a plant selection on the basis of grain percentage and anticipate with a high degree of certainty that the progeny will be true to the parent for this character. On the basis of these results, it seems that it should be an easy matter to develop a strain of corn with a high grain percentage. Whether this can be done without affecting the yield unfavorably leads to a consideration of the relation between grain percentage in the parent and yield in the progeny

GRAIN PERCENTAGE WITH YIELD

Table 4 presents the coefficients of correlation between grain percentage and yield

TABLE 4 —*Correlation coefficients for grain percentage with yield*

Year	Mosby	Cocke's Prolific	Laguna	Goliad
1925	———	—.0259±.0744	———	———
1926	—.0258±.0547	.0966±.0584	———	.2510±.0635
1927	.0278± 0649	.1687±.0625	.1504±.0742	.0589±.0638
1928	.0909±.0644	.0894±.0669	.0599±.0635	.1048±.0654
1929	-.0066± 0621	2158±.0660	.0551± 0663	.0973±.0646
1930	.1551±.0596	.1709±.0655	———	.0380±.0642

The coefficients are too small to be taken as statistically significant. However, there is a strong tendency to remain positive. Only 3 out of 19 are negative and the greatest of these is — .0259. When this is considered, it seems likely that there may be a slight relation between parent grain percentage and progeny yield.

These results indicate that under the system of breeding used in this experiment the inherent yielding ability of a selected plant cannot be determined by its grain percentage.

YIELD WITH GRAIN PERCENTAGE

The coefficients for yield with grain percentage are presented in Table 5.

TABLE 5.—*Correlation coefficients for yield with grain percentage.*

Year	Mosby	Cocke's Prolific	Laguna	Goliad
1925	———	—.0086±.0745	———	———
1926	-.0841±.0543	.1920±.0568	- - -	.1765±.0657
1927	1142±.0641	.1209±.0634	-.0949±.0752	.0353±.0639
1928	.0377±.0648	—.0052±.0675	.1557±.0622	.1499±.0647
1929	.1009±.0615	.0722±.0688	.1525±.0649	.2478±.0612
1930	0012±.0611	.0885±.0669	———	.1602±.0627

It will be seen that these coefficients are too small to be considered significant from the statistical point of view. However, as in the cases of yield with yield and grain percentage with yield, most of the coefficients are positive, there being only four that are negative, none of which are in the first decimal. If correlation exists at all it is too slight to be of any practical importance. Since no very strong correlation was shown to exist between yield and yield or between grain percentage and yield, it could hardly be expected that yield and grain percentage are strongly correlated.

SUMMARY

Parent-progeny correlations involving yield and grain percentage have been studied in connection with the corn breeding work of the Mississippi Experiment Station. This system of breeding has been described and the coefficients of correlation reported

Yield with yield gave 15 positive and 4 negative coefficients, all of which are small and of doubtful significance. The preponderance of positive values may indicate a tendency for high-yielding parents to produce high-yielding progenies. This tendency is so slight that it has no practical value to the breeder.

Grain percentage with grain percentage was strongly correlated, the coefficients ranging from .5267 ± .0441 to .8066 ± .0237.

Grain percentage with yield showed positive coefficients in 16 cases and negative in 3. The correlations were slight and of doubtful significance and indicate that within certain limits, at least, grain percentage is not an index of the inherent yielding power of a parent plant.

Yield with grain percentage gave 15 positive and 4 negative coefficients ranging from — .0949 ± .0752 to .2478 ± .0612.

These results agree with earlier conclusions that a system of corn improvement must use measures other than studies of the selected plant's characteristics.

THE RELATIVE VARIABILITY OF CORN CROSSES AND VARIETIES[1]

LLOYD E. ARNOLD and MERLE T. JENKINS[2]

It is a matter of common observation that corn varieties, single crosses, inbred-variety crosses, and double crosses differ in their relative variability. The present investigation was conducted to determine the differences in the amount of variability of varieties and these three kinds of crosses as measured by the standard deviations and coefficients of variation for various characters. The characters studied were plant height, ear height, total number of nodes, number of nodes below the upper ear, and number of kernel rows on the ears. Only the heights and numbers of nodes above the soil surface were measured or counted.

Data were taken on the plants in one replication of a yield comparison grown at Ames, Iowa, in 1930. The plats were planted thickly and thinned to fairly uniform stands. The average number of plants measured per plat was 36.3, with a maximum of 42 where the stand was perfect. The kernel rows were counted on the ears in a 50-pound drying sample of ear corn of each variety and cross.

The experiment included 12 varieties, 53 single crosses, 22 inbred-variety crosses, and 49 double crosses. The varieties were all standard Iowa varieties and represented fairly well the range of varieties grown in all sections of the state. The 53 single crosses represented all but 2 of the 55 possible combinations among 11 inbred lines. The 22 inbred-variety crosses were all made with the variety Four County White as the staminate parent. Most of the 49 double crosses involved single-cross combinations identical with those in the experiment but made one year earlier. The parental lines had been inbred 5 and 6 years when used in the double crosses, and one generation longer when used in the single crosses and inbred-variety crosses.

The minimum, mean, and maximum standard deviations and coefficients of variability are recorded in Table 1. The mean standard deviations are the root-mean-squares of the individual standard devi-

[1]Joint contribution from the Farm Crops Section, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Journal paper No. B43 of the Iowa Agricultural Experiment Station. Received for publication March 29, 1932.

[2]Formerly graduate student, Department of Farm Crops, Iowa State College, and Associate Agronomist, U. S. Dept. of Agriculture, respectively.

TABLE 1.—*Standard deviations and coefficients of variability for five characters in corn varieties and crosses.*

Characters	12 varieties			53 single crosses			22 inbred-variety crosses			49 double crosses		
	Min.	Mean	Max.	Min	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
					Standard Deviations							
Plant height, inches	5.00	7.24	9.99	2.86	5.43	7.30	4.18	6.57	8.66	3.81	6.26	7.98
Ear height, inches	4.10	5.65	7.47	2.52	3.67	5.63	2.78	4.68	5.91	3.32	4.69	6.52
Nodes per plant	1.10	1.36	1.77	0.55	0.82	1.08	0.85	1.05	1.26	0.69	1.05	1.42
Nodes below ear	0.79	1.14	1.48	0.46	0.70	0.97	0.65	0.85	1.08	0.69	0.90	1.17
Kernel rows	1.76	2.16	2.56	1.05	1.46	3.00	1.37	1.60	2.11	1.21	1.62	2.06
					Coefficients of Variability							
Plant height, inches	8.8	11.1	16.3	4.2	8.5	12.9	6.9	10.7	14.3	5.8	9.7	13.3
Ear height, inches	13.8	17.4	23.5	7.1	11.5	19.7	11.4	15.2	19.5	9.7	14.3	21.8
Nodes per plant	7.3	9.5	13.5	3.7	6.1	8.2	6.3	7.7	9.1	4.8	7.6	11.3
Nodes below ear	10.6	15.9	27.4	5.5	10.0	14.7	9.9	12.2	15.1	9.0	12.6	15.6
Kernel rows	10.5	12.9	16.5	7.5	10.0	17.6	8.6	10.7	12.6	9.4	11.6	16.0
Mean C. V.		13.4			9.2			11.3			11.2	

ations within each group. The mean coefficients of variability are the quotients of these divided by the mean values for the corresponding characters.

The varieties were most variable and the single crosses were least variable. The inbred-variety crosses and double crosses were approximately midway in variability between the varieties and the single crosses, and were not significantly different. The means of the mean coefficients of variability for the five characters studied were 9.2, 11.2, 11.3, and 13.4 for the single crosses, double crosses, inbred-variety crosses, and varieties, respectively. When rated on the basis of these means, with that of the single crosses as 100, the double crosses rated 122, the inbred-variety crosses 123, and the varieties 146.

A more detailed comparison was made of the coefficients of variability for single crosses and inbred-variety crosses. The 11 inbred lines used as parents of the single crosses also were crossed with the Four County White variety The mean coefficient of variability for each character in the single crosses of each line was paired and compared directly with that of the inbred-variety cross for the same line. The means and the mean differences are recorded in Table 2

TABLE 2 —*Coefficients of variability for Four County White, inbred-variety crosses with Four County White and single crosses.*

Character	Coefficients of variability			Difference
	Four County White	Inbred-variety crosses	Single crosses	
Plant height, inches	11.7	11.2	8.4	2.8±0.32
Ear height, inches	17.0	16.1	11.4	4.7±0.33
Nodes per plant	9.6	7.4	6.0	1.4±0.18
Nodes below ear	11.9	12.0	9.9	2.1±0.36
Kernel rows per ear	13.1	10.5	9.9	0.6±0.17

All of the differences between inbred-variety crosses and single crosses are significant, as judged by their probable errors. The inbred-variety crosses did not differ greatly in variability from the parent variety, Four County White, in plant height, ear height, and nodes below ear. The coefficients of variability for Four County White, however, are based on only one plat of 34 plants.

The data on the single crosses and the double crosses were studied to determine any relation which might exist between the variability of the double crosses and that of their component single crosses. The only relations indicated, however, were so small as to be unimportant.

Under most conditions differences in the variability of the different types of crosses will have little influence upon the breeding methods

employed as compared with the more important considerations such as acre yield and quality. It has been suggested that the extreme uniformity of single crosses might render them objectionable under some conditions because all of the plants express their maximum demands at the same time. Unfavorable conditions at this time would result in unduly great injury. If this is the case the types of crosses with greater inherent variability should give better results over a period of years. In sweet corn breeding, however, uniformity, particularly in the matter of maturity, is of great importance In this case single crosses should have a decided advantage over either inbred-variety crosses or double crosses.

THE COLD RESISTANCE OF PACIFIC COAST SPRING WHEATS AT VARIOUS STAGES OF GROWTH AS DETERMINED BY ARTIFICIAL REFRIGERATION[1]

J. FOSTER MARTIN[2]

Certain varieties of spring wheat are commonly fall sown in the Columbia River Basin of eastern Oregon. Their early maturity often enables them to escape hot winds and severe summer drought at a critical period of development. A recent survey by Hill (3)[3] showed that Federation, a white spring wheat, is more uniformly distributed over the dry-land section of Oregon than any other variety. A large percentage of the Federation acreage is sown in the fall. Jenkin and some of the other spring varieties are also fall sown to a limited extent. Field observations indicate that distinct differences in winter hardiness exist between many of the spring wheat varieties grown in this section. The snow covering often is sufficient to prevent

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Oregon Agricultural Experiment Station, Corvallis, Ore. Submitted in part to the Kansas State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of master of science. Received for publication April 16, 1932.

[2]Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, cooperative cereal agronomy, Pendleton Field Station, Pendleton, Ore., formerly at the Sherman County Branch Station, Moro, Ore. The writer acknowledges valuable suggestions from S. C. Salmon, formerly professor of farm crops, Kansas State College, and now principal agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, in outlining and conducting these experiments and to the Kansas State College of Agriculture and Applied Science for providing facilities for carrying them out.

[3]Reference by number is to "Literature Cited," p. 880.

severe injury to the plants even when the winter temperature falls below zero, but considerable winterkilling sometimes results and reseeding is necessary. Consequently, the relative winter hardiness of varieties is important. Late spring frosts also may injure early varieties.

Mild winters in many years, protective snow covering, and other factors add to the difficulty of obtaining accurate data on winter hardiness in the field. The experiments herein reported were conducted primarily to determine the value of artificial refrigeration as a means of measuring cold resistance in relatively nonhardy varieties, and to find if relative resistance remains constant at different periods of growth.

MATERIALS AND METHODS

Artificial refrigeration was effected by means of the direct expansion, thermostatically controlled carbon dioxide refrigeration plant described by Sellschop and Salmon (6). Most of the plants were grown in the greenhouse in flats. Twelve plants of each variety were grown in each flat by sowing the varieties in 12-inch rows, 2 inches apart. Competition between varieties in a flat was not a factor with plants frozen in the seedling stage but became more important in the later stages of growth. Thin rows tended to be injured more than those with a normal stand. Particular care was taken to have a uniform moisture supply in all the flats at the time of freezing. All flats were placed outdoors soon after the plants had emerged to permit the varieties to harden under natural conditions.

A uniform freezing period of 12 hours was used, as considerable time is necessary for soil temperatures to approach those of the freezing chamber. The relative resistance of the varieties to low temperatures was measured in two ways, *viz.*, by estimating the percentage of tissue apparently killed, and by determining the percentage of plants killed. The percentage of leaf injury was estimated 1 week after freezing. The percentage of plants killed could not be determined accurately until about 2 weeks after freezing. Since it was desired to note how accurately resistance could be measured by estimates of leaf injury, both sets of data are given in most cases. Twelve varieties of spring wheat commonly grown in the Columbia River Basin were used in all studies. Hybrid 128, a variety with a winter growth habit, was included as a hardy check. Percentages of injury for this variety are given, but the results are not used in calculating the coefficients of correlation.

Because of the nature of the data, it was convenient to calculate coefficients of correlation from varietal ranks, Spearman's formula, p (Rho) $= 1 - \frac{6\Sigma d^2}{n(n^2-1)}$, being used, which results in coefficients differing but slightly from those obtained directly from the scores. Probable errors were calculated by Pearson's formula, P. E. $p = 0.7063 \frac{1-p^2}{\sqrt{n}}$, which Kelley (4) states gives a figure about 5% greater than the probable error of r.

EXPERIMENTAL RESULTS

All flats containing plants were placed outside soon after emergence and exposed to natural conditions prevailing during the fall, but a part of them were brought into the greenhouse a few days before freezing to determine if freezing in an unhardened condition would in any way affect the relative response of the different varieties. Hence it has seemed desirable to present the results separately.

COLD RESISTANCE OF HARDENED PLANTS

About 175 plants of each variety of the hardened group were frozen at a minimum temperature of approximately 11°F about 8 weeks after emergence. Table 1 gives rank, average percentage of

TABLE 1. —*Relative winterkilling in the Columbia Basin of Oregon and injury by artificial refrigeration of plants hardened before freezing.*

Variety	C. I No.*	Field winterkilling		Artificial refrigeration			
		Percentage of Federation	Hardiness rank	Estimated injury		Plants killed	
				%	Hardiness rank	%	Hardiness rank
Galgalos sel	11,385	17.9	1	29.1	6	4.9	7
Hybrid 123	4,511	19.0	2	8.8	2	0.8	2
Hybrid 63	4,510	28.0	3	7.2	1	0.4	1
Hard Federation x Martin	11,488	32.0	4	33.1	8	3.5	5.5
Hybrid 143	4,513	33.2	5	22.3	3	2.3	3
Red Chaff sel	11,404	41.3	6	32 9	7	8.1	9
Little Club	4,066	53.4	7	22.7	4	3.5	5.5
Hood	11,456	67.2	8	27.9	5	3.0	4
Jenkin	5,177	71.6	9	50.7	9	6.8	8
Pacific Bluestem	4,067	73.8	10	66.5	10	41.4	10
Federation	4,734	100.0	11	93.1	11	60.8	11
Hard Federation	4,733	133.0	12	96.0	12	93.4	12
Hybrid 128	4,512	—	—	3.3	—	0	—

*C. I. refers to accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

leaf injury, and percentage of plants killed of all varieties in the experiment. The winterkilling and rank of the varieties in field experiments in the Columbia Basin of Oregon also are shown. Since the latter are for a variable number of years at four different locations, they are summarized in comparison with Federation. This variety was included in all experiments where records of winter survival were obtained. Although open to criticism, this method probably is the most satisfactory available, considering the limited data.

The agreement between injury in the field and injury by artificial refrigeration was in general very good. The correlation coefficient between rank based on winterkilling and estimated injury is 0.762 ± 0.085 and that between winterkilling and plants killed by artificial refrigeration 0.740 ± 0.092.

It apparently makes little difference whether the response to low temperatures is measured by leaf injury or by plants killed, the correlation coefficient for the two being 0.946 ± 0.021. In some cases, as for example in comparing Federation and Hard Federation, the differences in plants killed are much greater and hence more clearly apparent than are those for estimated injury to the leaves.

An important exception to the agreement between field results and artificial refrigeration was observed in respect to the Galgalos selection. In the field this variety was on the average injured but little more than true winter wheats. Possibly Galgalos owes its relatively high winter hardiness to factors other than cold resistance, as Salmon (5) and others have pointed out that other factors may be of considerable importance.

COLD RESISTANCE OF UNHARDENED PLANTS

Flats containing approximately 60 plants of each variety were taken into the greenhouse and kept 5 days under conditions favoring rapid growth before being frozen. Previous work (1) had shown that most of the acquired hardiness is lost within this time. Table 2 gives the percentage injury and rank of varieties that had been frozen at a minimum temperature of about 15°F.

Although the unhardened plants were frozen at temperatures averaging 4°F higher, the percentage of injury was always greater than that of the hardened plants. In this respect the hardier varieties showed greater differences than did the tender varieties.

Differences in hardiness between varieties were more sharply defined in hardened than in unhardened plants. Nevertheless, the correlation coefficient for winterkilling in the field and estimated injury based on rank was 0.636 ± 0.121. Based on plants killed

instead of on estimated injury, the correlation coefficient was 0.761 ± 0.086. Again it made but little difference whether response to artificial refrigeration was measured by leaf injury or by plants killed, the coefficient being 0.911 ± 0.035.

TABLE 2.—*Percentage of estimated injury, plants killed, and hardiness rank of varieties as determined by artificial refrigeration of unhardened plants.*

Variety	C. I. No.	Artificial refrigeration			
		Estimated injury		Plants killed	
		%	Hardiness rank	%	Hardiness rank
Galgalos sel	11,385	67.0	9	14.8	6
Hybrid 123	4,511	35.2	3	11.4	5
Hybrid 63	4,510	30.0	2	7.6	2
Hard Federation x Martin	11,488	53.0	6	11.0	4
Hybrid 143	4,513	28.0	1	3.6	1
Red Chaff sel	11,404	35.6	4	8.0	3
Little Club	4,066	63.0	8	34.0	9.5
Hood	11,456	51.0	5	24.0	7
Jenkin	5,177	62.0	7	31.0	8
Pacific Bluestem	4,067	78.0	10	34.0	9.5
Federation	4,734	96.0	11	85.0	11
Hard Federation	4,733	99.0	12	98.8	12
Hybrid 128	4,512	13.2	—	2.9	—

TIME OF HEADING AND COLD RESISTANCE

In general an association is considered to exist between time of heading and winter hardiness, particularly in varieties having a winter growth habit. Suneson (7) found a correlation coefficient of — 0.452 ± .0015 between cold resistance and time of heading of 13 winter wheats. The relationship is not so close with the spring varieties used in these experiments. Table 3 shows the rank of varieties based on time of heading, winterkilling in the field, leaf injury, and plants killed as determined by artificial refrigeration.

The hardy varieties in these experiments tend to be late. In earliness of heading Hard Federation, Federation, and Pacific Bluestem, the least hardy of the wheats in the experiment, ranked first, second, and fourth, respectively. The variety Jenkin, however, is one of the latest wheats in the group and also one of the least hardy. The correlation coefficient between time of heading and winterkilling under field conditions was — 0.280 ± 0.188. The correlation coefficients for date of heading and leaf injury and for date of heading and plants killed by artificial refrigeration were — 0.587 ± 0.133 and — 0.350 ± 0.179, respectively. Only one of these coefficients is significant in relation to its probable error. It would appear that while late heading indicates resistance to cold in many varieties, the

association is not sufficiently constant to permit time of heading to be considered an accurate index of hardiness in the spring wheats used in these experiments.

TABLE 3.—*Hardiness rank of varieties based on time of heading, winterkilling in the field, leaf injury, and plants killed as determined by artificial refrigeration.*

Variety	C. I. No.	Hardiness rank based on			
		Time of heading	Cold resistance		
			Winter-killing	Artificial freezing	
				Estimated injury	Plants killed
Galgalos sel.	11,385	5	1	8	5
Hybrid 123	4,511	9	2	2	3
Hybrid 63	4,510	9	3	1	1
Hard Fed. x Martin	11,488	3	4	7	4
Hybrid 143	4,513	6	5	3	2
Red Chaff sel	11,404	7	6	5	6
Little Club	4,066	9	7	4	8
Hood	11,456	12	8	6	7
Jenkin	5,177	11	9	9	9
Pacific Bluestem	4,067	4	10	10	10
Federation	4,734	2	11	11	11
Hard Federation	4,733	1	12	12	12

COMPARISON OF DAY AND NIGHT FREEZING

Davis (2) observed in his experiments that plants frozen during the day were injured more severely than those frozen at night. His explanation is that photosynthetic activity builds up the resistance of the plant during the day by increasing the carbohydrate content and the cell sap concentration, whereas at night the reverse is true. Table 4 compares the leaf injury and plants killed of plants frozen during the day and at night.

Without exception the average leaf injury was less for plants frozen at night, the average of all varieties being 50.6% for day freezing compared to 34.0% for plants frozen at night. The ranks remained about the same except for two or three varieties, the correlation coefficient being 0.818 ± 0.067.

The difference in percentage of plants killed was not so pronounced, as the average for all varieties was only 4.5% more for day than for night freezing. The correlation coefficient for day and night freezing using this criterion was 0.750 ± 0.089.

COLD RESISTANCE IN THE BOOT STAGE

Late spring frosts are an important hazard in spring wheat production at high altitudes, as they often occur about the time the spikes begin to form. The varieties listed in Table 5 were frozen

TABLE 4.—*Comparison of leaf injury and plants killed by day and night freezing of hardened plants.*

Variety	C. I. No.	Leaf injury				Plants killed			
		Day		Night		Day		Night	
		Injury %	Hardiness rank	Injury %	Hardiness rank	Injury %	Hardiness rank	Injury %	Hardiness rank
Galgalos sel	11,385	33.0	3	24.0	8	3.7	5	6.2	8
Hybrid 123	4,511	12.2	2	6.7	2	1.0	2	0.9	3
Hybrid 63	4,510	10.2	1	5.5	1	0.5	1	0.4	1
Hard Federation x Martin	11,488	41.7	7	22.0	7	2.0	3	2.4	6
Hybrid 143	4,513	39.7	6	8.7	3	4.5	6	0.5	2
Red Chaff sel	11,404	58.5	8	15.5	4	16.0	9	1.5	4.5
Little Club	4,066	34.2	4	16.4	5	6.0	7	1.5	4.5
Hood	11,456	36.7	5	21.9	6	2.7	4	3.7	7
Jenkin	5,177	59.2	9	44.4	9	6.7	8	7.7	9
Pacific Bluestem	4,067	84.7	10	48.2	10	48.4	10	31.4	10
Federation	4,734	97.5	11	95.4	11	66.7	11	52.5	11
Hard Federation	4,733	100.0	12	99.5	12	94.5	12	90.9	12
Average		50.6		34.0		21.1		16.6	

when near the boot stage to test their reactions at this period of growth. The plants were grown in the greenhouse prior to freezing. Since all varieties were sown on the same date they were not in identical stages of development when frozen, and this fact no doubt influenced the results to some extent. However, no constant relation between hardiness and stage of development was observed in this test.

Preliminary experiments showed that differences between varieties were rather small at this stage of growth. Thus all plants were killed when subjected to a minimum temperature of 16°F and no injury occurred when they were subjected to a temperature of 22°F. A group containing 120 plants of each variety frozen at a minimum temperature of about 19°F gave differential results, as shown in Table 5.

TABLE 5.—*Average estimated injury to varieties of spring wheat subjected to freezing temperatures in the boot stage of development.*

Variety	C. I. No.	Artificial freezing	
		Injury %	Hardiness rank
Galgalos sel	11,385	51.9	3
Hybrid 123	4,511	47.3	1
Hybrid 63	4,510	57.5	7
Hard Federation x Martin	11,488	55.0	5
Hybrid 143	4,513	55.0	5
Red Chaff sel	11,404	51.3	2
Little Club	4,066	55.0	5
Hood	11,456	66.3	10
Jenkin	5,177	60.0	8
Pacific Bluestem	4,067	72.5	11
Federation	4,734	63.8	9
Hard Federation	4,733	73.4	12
Marquis	4,158	67.3	—
Average*		59.1	

*Excluding Marquis.

In some instances the leaves and heads were killed, although the culms showed no injury for 3 or 4 days. The varieties were ranked according to percentage of plants killed and correlated with winter-killing in the field, as previously described. The correlation coefficient was 0.818 ± 0.067. The coefficients for plants killed in the boot stage, on the one hand, and for estimated injury and plants killed in the seedling stage, on the other hand, were 0.643 ± 0.119 and 0.671 ± 0.112, respectively. It would appear from these data that although varieties differ less in resistance to low temperature at this stage of growth than when in earlier stages of development, such differences

as exist are in agreement with the resistance in earlier stages and also with winterkilling under field conditions.

COLD RESISTANCE AT TIME OF HEADING

As a further check on the relative cold resistance at different stages of development, 20 4-inch pots of five plants each of Galgalos selection, Pacific Bluestem, and Hard Federation were frozen soon after they had reached the heading stage. They were sown at different times to bring them to the heading stage together. They were frozen at a minimum temperature of about 19°F.

An average of 4.4 plants per pot of Pacific Bluestem and 1.6 plants per pot of Galgalos selection and all plants of Hard Federation were killed. The treatment was too severe for completely satisfactory results, especially for a comparison of Hard Federation and Pacific Bluestem. It appears, however, that Hard Federation was clearly more susceptible to injury than was Pacific Bluestem, and Galgalos was injured much less than either of the others. These results are entirely in accord with winterkilling of the varieties under field conditions and with the same varieties when frozen in the seedling and boot stages.

SUMMARY AND CONCLUSIONS

Relative winter hardiness of varieties of spring wheat is an important ecological factor in the Columbia Basin of Oregon. Experiments were conducted to determine the value of artificial refrigeration as a means of studying cold resistance in relatively nonhardy varieties, and to find if relative resistance remains constant at different periods of growth. Some of the plants were frozen after being hardened under natural conditions by exposure outside the greenhouse. Others were frozen in an unhardened condition.

The varieties were ranked according to winterkilling under field conditions in the Columbia Basin and according to injury in the artificial freezing tests, and the correlation coefficients for these ranks were calculated. The coefficient for winterkilling under field conditions and estimated injury of hardened plants frozen in the seedling stage of development was 0.762 ± 0.085. The coefficient between field survival and the percentage of plants killed by artificial freezing was 0.740 ± 0.092. In some instances the differences in cold resistance were shown better by the percentages of plants killed than by leaf injury.

Correlation coefficients of 0.636 ± 0.121 and 0.761 ± 0.086 were obtained from a comparison of field results with leaf injury and

plants killed, respectively, of unhardened plants in the seedling stage. The average injury of unhardened plants was greater than that of hardened plants, especially for the hardy varieties even though frozen at higher temperatures.

The association between time of heading and resistance to cold was not sufficiently constant to permit the use of the former as an index of hardiness.

The average leaf injury was greater for plants frozen during the day than during the night, but the difference based on percentage of plants killed was not pronounced.

The correlation coefficient between field results and plants frozen when in the boot stage of development was 0.818 ± 0.067. A comparison of injury in the boot stage with data on leaf injury and plants killed in the seedling stage gave correlation coefficients of 0.643 ± 0.119 and 0.671 ± 0.112, respectively, indicating a definite relation. The varieties in this experiment, however, differ relatively little in cold resistance when actively growing near the boot stage.

Results from freezing varieties in the heading stage were in accord with winterkilling under field conditions and with cold resistance in the seedling and boot stages. Differences between varieties are small, however, and differentiation of varieties at this stage of development appears to be difficult.

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EFFECT OF NITRATE OF POTASH ON THE VIGOR AND PRODUCTIVITY OF HEALTHY AND LEAF-ROLL GREEN MOUNTAIN POTATO PLANTS AND THEIR PROGENIES[1]

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In the course of an investigation on the effect of temperature on the growth and productivity of successive generations of healthy and leaf-roll Green Mountain potatoes, it was noticed that nitrate of potash applied to some of the cultures not only increased yields but also resulted in loss of vigor in the progeny of the fertilized plants. These results were deemed of sufficient interest to warrant a note, especially since Wartenberg[3] recently advanced the suggestion that degeneration may result from the use of excessive potash fertilization.

METHODS

The plants were grown in galvanized iron pails 9 inches high and 10½ inches wide on top with a 1 inch drainage hole in the bottom over which a 3-inch flower pot saucer was inverted before they were filled with soil. The potting soil was screened, air-dried, and thoroughly mixed before being placed in the pails. The soil was added to the pails in two installments, the volume amount used in 1930 and 1931 being approximately the same though the weighed amount was different owing to the fact that in the latter year approximately 3% of ground peat was added to increase resiliency. In 1930, 4,000 grams and in 1931, 3,000 grams of soil were placed in the pots, uniformly compacted by striking on a hard surface, then stood in water which rose slowly through the drain holes and eventually flooded the surface of the soil. As soon as the surface of the soil in all the pots was covered with water they were removed and allowed to drain until the water just disappeared from the surface when the drainage holes were stoppered with rubber corks. The pots were weighed and the amount of water required to saturate the soil determined. The stoppers were then removed and the pots allowed to stand until the water in the soil reached 60% of saturation. As soon as the soil was sufficiently dry, the seed was planted and covered with 3,900 grams of air-dry soil in 1930 and 3,000 grams in 1931, and the pots tamped as before to compact it thoroughly. Since the amount of water required to saturate the soil added could not be determined directly, it was assumed to be equal to the mean value obtained for

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[3]WARTENBERG, H. Beitrag zur Kenntnis des okologischen Abbaues der Kartoffel. Arb. Biol. Reichsanst fur Land- und Forstwirtsch., 18: 405–423. 1931.

the soil first added. Water was added to the pots in sufficient quantity to bring the total amount present up to 60% of saturation for the entire amount of soil used.

After the experiments were started the pots were brought up to weight daily. In 1930, there were four series of plants in each of the healthy and leaf-roll groups, and in 1931 eight series in each. The set up of the experiment is described below.

1930 ARRANGEMENT

Healthy plants.—Ten tubers weighing somewhat over 50 grams were bisected longitudinally and the halves grown one at 15°C and the other at 20°C. All plants in each series grew.

Healthy plants fertilized.—As above, except that nitrate of potash was applied in powder form on the surface of the soil before the plants came up at the rate of 15 grams per pot, that is in amount approximately equal to 2 parts per thousand of the air-dry weight of the soil. All plants in each series grew.

Leaf-roll plants.—As above. During the growing season two plants in the series grown at 15°C developed mosaic symptoms and were discarded as were also the two pots containing the sister half tubers in the series at 20°C. The weight of the tubers used, discarding rejected plants, ranged between 60 and 90 grams, mean 74 grams. Eight plants in each series reached maturity.

Leaf-roll plants fertilized.—As above, except for the addition of nitrate of potash. Four plants were removed from each series, either because sister seed pieces did not grow, or were so weak as to be outside the range of their group. The weight of the tubers used, discarding rejected plants, ranged between 62 and 92 grams, mean 76 grams. Six plants in each series reached maturity.

1931 ARRANGEMENT

One potato of suitable size to give individual seed pieces of 20 to 25 grams in weight was taken from the harvest of each pot, bisected longitudinally, and the daughter halves grown at approximately the same mean low and high temperatures that were used in 1930. The remaining tubers from each pot were planted whole in beds and grown at 15°C for the purpose of ascertaining whether there had been any disease transmission. The seed from the healthy plants developed healthy plants in all cases, and the seed from the leaf-roll plants, leaf-roll plants only. In 1932, the tubers produced by the plants grown in 1931 were again grown in beds at 15°C. The tubers from healthy plants produced only healthy plants and the seed from leaf-roll plants, leaf-roll plants only.

In 1931, the nitrate of potash was applied at the rate of 2 parts per thousand of the air-dry weight of the soil in two equal installments.

During 1930 and 1931, care was taken in handling the plants to prevent disease transmission, and insects were held in control by appropriate treatments.

EXPERIMENTAL

1930 RESULTS

The growth of the healthy plants at 20°C was not affected by the nitrate of potash during the first 45 days from date of planting, but at 15°C growth of the fertilized plants was somewhat slower though the color of the foliage, especially towards the close of the growing season, was a much deeper green.

In the case of the leaf-roll plants at both temperatures growth was retarded by the nitrate of potash though the plants grown at the lower temperature were less affected than those grown at the higher. The effect produced by the nitrate of potash on the rate of growth of the healthy and leaf-roll plants was quite marked, as shown by the data presented in Table 1. The plants were harvested 103 days after planting and the mean yields per plant, excluding tubers weighing less than 15 grams, and the mean number of tubers per plant are presented in Table 2.

TABLE 1.—*Effect of nitrate of potash on the growth of healthy and leaf-roll Green Mountain potatoes.*

Kind of plant and treatment	Mean haulm length in cm					
	Plants grown at 15°C			Plants grown at 20°C		
	45 days from planting	53 days from planting	Increase %	45 days from planting	53 days from planting	Increase %
Healthy.	11.93	23.20	94.5	29.45	31.90	8.3
Healthy fertilized. .	10.82	18.95	75.1	28.66	35.05	22.2
Leaf-roll.	9.75	18.41	88.8	27.19	28.23	3.8
Leaf-roll fertilized. .	9.66	14.21	47.1	17.90	17.88	—0.11

In the healthy plants the nitrate of potash increased the yield of the plants grown at 15°C by 33.5% and in those grown at 20°C by 18.7%. In the case of the leaf-roll plants grown at 15°C the increas was 12.2%, but in those grown at 20°C there was a loss of 5.2%. In both the healthy and leaf-roll plants the response to the nitrate of potash was not as favorable in the plants grown at 20°C as in those grown at 15°C. The decrease in yield in the case of the former was 14.8% and in the case of the latter 17.4%, figures which indicate that the depressing effect of the nitrate of potash was of a similar order of magnitude in both the healthy and leaf-roll plants grown at 15°C.

TABLE 2.—*Effect of nitrate of potash on yield and tuber set of healthy and leaf-roll Green Mountain potatoes.*

Kind of plant	Plants grown at 15°C				Plants grown at 20°C			
	Not fertilized		Fertilized		Not fertilized		Fertilized	
	Mean weight per plant, grams	Mean No. of tubers per plant	Mean weight per plant, grams	Mean No. of tubers per plant	Mean weight per plant, grams	Mean No. of tubers per plant	Mean weight per plant, grams	Mean No. of tubers per plant
Healthy....	516.70	7.10	690.12	8.62	489.80	7.30	581.87	8.37
Leaf-roll...	358.25	8.75	402.00	9.50	380.37	8.50	360.33	7.50

TABLE 3.—*Effect of temperature and nitrate of potash on the vigor of the second generation of Green Mountain potatoes.*

Method of handling*	Mean length of haulm in cm													
	23 days from planting		30 days from planting				38 days from planting				45 days from planting			
	Plants not fer-tilized	Plants fer-tilized	Plants not fer-tilized	In-crease %	Plants fer-tilized	In-crease %	Plants not fer-tilized	In-crease %	Plants fer-tilized	In-crease %	Plants not fer-tilized	In-crease %	Plants fer-tilized	In-crease %
							Healthy Plants							
c 1930, c 1931	8.71	10.75	15.08	73.1	15.75	46.5	22.78	51.0	21.62	37.2	21.81	—4.2	21.55	—0.3
c 1930, w 1931	18.59	21.44	34.08	83.3	26.05	21.5	37.13	8.9	28.33	8.7	36.43	—1.8	31.23	10.2
w 1930, w 1931	13.46	17.45	25.14	86.7	26.15	49.8	30.64	21.8	27.69	5.8	31.34	2.2	28.76	3.8
w 1930, c 1931	5.50	5.70	12.08	117.8	9.64	69.1	16.23	34.3	14.00	45.2	19.77	21.8	16.09	14.9
							Leaf-roll Plants							
c 1930, c 1931	5.00	4.00	9.13	82.6	6.50	62.5	14.20	55.5	11.00	69.2	15.75	10.9	11.87	7.9
c 1930, w 1931	15.00	9.00	22.46	49.7	12.77	41.8	23.46	4.4	15.22	19.1	24.53	4.5	15.55	2.1
w 1930, w 1931	13.15	9.50	16.84	28.0	12.36	30.1	18.89	12.1	12.00	—2.9	20.05	6.1	14.09	17.4
w 1930, c 1931	3.23	2.88	6.47	100.3	4.88	69.4	10.50	62.2	7.22	11.5	11.31	7.7	8.55	18.4

*c=plants grown at 15°C; w=plants grown at 20°C.

1931 RESULTS

One tuber from the crop of each plant grown in 1930 was bisected longitudinally and the halves planted at 15°C and 20°C, respectively. Since there were four groups of plants in the 1930 experiment, there were 8 series of plants in the 1931 experiment distributed as follows: Healthy and leaf-roll plants with and without nitrate of potash grown at 15°C in 1930 and 1931 (c 1930-31); healthy and leaf-roll plants with and without nitrate of potash grown at 20°C in 1930 and 1931 (w 1930–31); healthy and leaf-roll plants with and without nitrate potash grown at 15°C in 1930 and at 20°C in 1931 (c 1930, w 1931); and healthy and leaf-roll plants with and without nitrate of potash grown at 20°C 1930 and 15°C in 1931 (w 1930, c 1931).

The data for the rate of growth of the plants in the several series are presented in Table 3. It will be noticed that in the case of the healthy plants 23 days after planting, the growth of the plants receiving nitrate of potash was greater than in the non-fertilized in all series In the c to w series and the w to c series, the mean haulm length was less in the fertilized than in the non-fertilized plants 30 days after planting. The length of the haulms was less in the fertilized than the non-fertilized plants in all series 38 and 45 days after planting.

In the case of the leaf-roll plants, the length of the haulms in the fertilized series was always less than in the corresponding non-fertilized series. In the case of the healthy plants the mean length of the haulms 45 days from date of planting was 1 1% less in the fertilized than in the non-fertilized plants in the c to c series; 14.2% less in the c to w series; 8.2% less in the w to w series; and 18.5% less in the w to c series. In the case of the leaf-roll plants the decrease in mean length of growth due to the nitrate of potash was 24.6% in the c to c series; 36.6% in the c to w series; 29.7% in the w to w series; and 24.4% in the w to c series.

The figures show that nitrate of potash decreased growth more markedly in the leaf-roll plants than in the healthy plants. On the other hand, the relative decreases in the different series show wider variations in the healthy plants than in the leaf-roll plants.

In 1930, the mean haulm length of the leaf-roll plants grown at 15°C was 20.6% less than in the healthy plants; in the leaf-roll fertilized plants, 25.0% less than in the healthy fertilized plants; while in the plants grown at 20°C the differences were 11.5% and 48.9%, respectively. In 1931, the mean haulm length of the leaf-roll plants grown at 15°C was much affected by the previous history of the plants. In the c to c series it was 27.7% and in the w to c series

42.7% less than that of the healthy plants. In the case of the plants grown at 20°C, on the other hand, previous history of the plants had no material effect, the mean length of haulm in the c to w series being 37.7% and, in the w to w series 36% less than in the healthy plants of the corresponding series.

In the case of the leaf-roll plants receiving nitrate of potash the decrease in mean length of haulm was marked, but it was not materially affected by the temperature at which the plants were grown or their previous history. The mean haulm length in the c to c series was 44.9%, in the w to c series 46.8%, in the c to w series 50.1%, and in the w to w series 51.0% less than in the healthy plants, figures which are of the same order of magnitude as those obtained in 1930 in the case of the fertilized series grown at 20°C.

When the plants were harvested, the differences in vigor just described were even more strikingly shown in the yields obtained, as will be seen from a consideration of the data presented in Table 4. A study of the table shows that in neither the healthy nor the leaf-roll plants of any series did nitrate of potash increase the yield. There is nothing unusual in the fact that the plants did not respond to the application of nitrate of potash in 1931 in the same way as in 1930. The soil used was not the same, but all things being equal we would expect the different series of fertilized plants in 1931 to respond in essentially the same way in respect to one another as in 1930 had the vitality of the tubers not been affected by the use of nitrate of potash in 1930. A study of the data presented in Tables 2 and 4 show that the leaf-roll plants grown at 15°C in 1930 yielded 42.2% less than the healthy plants grown at the same temperature and, using for terms of comparison the c 1930, c 1931 series, 49.3% less in 1931. The leaf-roll plants grown at 15°C to which nitrate of potash was applied yielded 22.1% less in 1930 than the healthy non-fertilized plants grown at the same temperature and, using for terms of comparison the c 1930, c 1931 series, 68.3% less in 1931. The leaf-roll plants grown at 20°C in 1930 yielded 24.4% less than the healthy grown at 15°C and, using for purposes of comparison the c 1930, w 1931 series with the c 1930, c 1931 series, 60.1% less in 1931. The leaf-roll plants to which nitrate of potash was applied in 1930 yielded 30.2% less than the healthy non-fertilized plants grown at 15°C, and again comparing the same respective series, 76.4% less in 1931.

The figures show that when leaf-roll potatoes were grown in 1930 and 1931 at 15°C, vigor and productivity of the plants in the nitrate of potash series were largely reduced. When the potatoes were

grown at 15°C in 1930 and at 20°C in 1931, vigor and productivity were greatly reduced though deterioration was not increased by the use of nitrate of potash.

TABLE 4.—*Effect of previous history and temperature at which grown on the yield of fertilized and non-fertilized healthy and leaf-roll Green Mountain potatoes.*

Method of handling*	Mean yield per plant in grams					
	Healthy plants			Leaf-roll plants		
	Plant not fertilized	Plant fertilized	Increase %	Plant not fertilized	Plant fertilized	Increase %
c 1930, c 1931	581.20	499.06	—14.1	294.12	183.7	—37.5
c 1930, w 1931	452.40	451.75	— 0.1	231.75	137.00	—40.8
w 1930, w 1931	440.65	380.31	—13.4	180.81	95.00	—47.4
w 1930, c 1931	524.16	358.12	—31.6	176.12	93.58	—46.8

*c = plants grown at 15°C; w = plants grown at 20°C.

In the case of the healthy plants, it will be noticed that the cultures grown at 15°C produced a 5.2% higher yield in 1930 than the cultures grown at 20°C, and 23.1% more in 1931.

The healthy plants fertilized and grown at 15°C in 1930 produced a 33.5% larger crop than the non-fertilized plants grown at the same temperature, but in 1931, comparing c 1930, w 1931 series with c 1930, c 1931 series, there was a decrease in yield of 14.1%.

The healthy plants receiving nitrate of potash and grown at 20°C in 1930 yielded 10.6% more than the healthy non-fertilized cultures grown at 15°C, but in 1931 there was a loss in yield of 22.2%.

In the case of the healthy plants the use of nitrate of potash in 1930 did not cause, in and by itself, decreased productivity, though when associated with change in temperature from one season to the next a distinctly injurious effect was produced when the fertilized plants were grown the first year at 20°C and the second at 15°C. In the case of the leaf-roll plants, on the other hand, the effect produced by the use of nitrate of potash was little if at all affected by changing the temperature at which the plants were grown during the second year.

FERTILIZER REQUIREMENTS OF SUGAR CANE ON YAZOO VERY FINE SANDY LOAM IN LOUISIANA[1]

A. M. O'NEAL, L. A. HURST, and S. J. BREAUX, JR.[2]

The Yazoo very fine sandy loam is one of the most extensively developed and important soils of the sugar cane district of Louisiana. It is the dominant soil type of the Mississippi Alluvium, First Bottom Soil Area, or that part of the state to the south and east of a sinuous line drawn from Morgan City north along the Atchafalaya River to

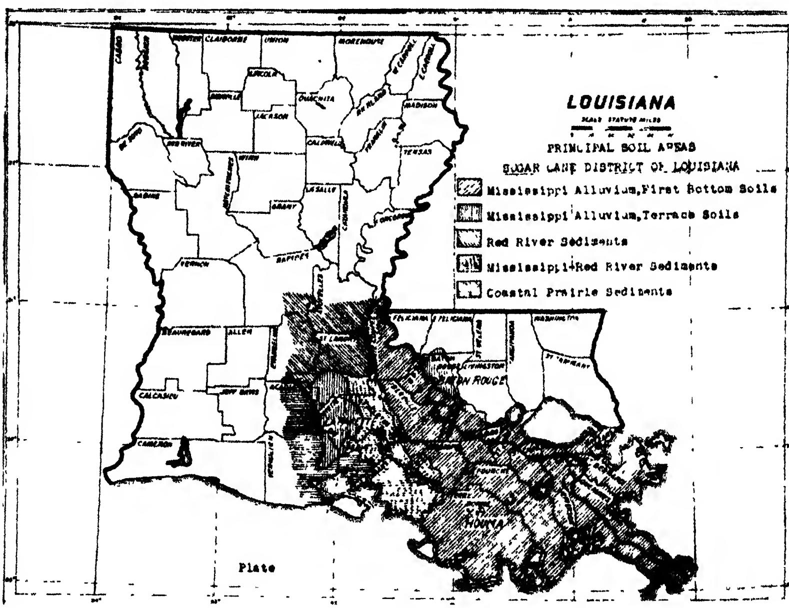

FIG. 1.—Map showing location and reconnaissance soil survey of Louisiana sugar cane belt.

Simmsport, down the east side of the Mississippi River to Placquemine, thence east to Lake Ponchartrain (Fig. 1). This type of soil occurs on practically every plantation and constitutes one of the most valuable sugar cane soils.

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Also presented before the joint meeting of the Society and Section O, of the American Association for the Advancement of Science, New Orleans, La., December, 1931. Received for publication March 16, 1932.

[2]Associate Soil Technologist and Biochemist, U. S. Dept. of Agriculture; and Assistant in Outfield Work, Louisiana Agricultural Experiment Station, respectively.

GENERAL SOIL CHARACTERISTICS

The Yazoo very fine sandy loam is of recent origin and occupies a first bottom position. It occurs as a low, natural levee bordering the rivers, bayous, and old drainage channels and is locally known as "Sandy Land." Along the Mississippi River it occurs in large connected areas that often extend from 1 to 2½ miles back from the river before merging with the heavier types. Where it occurs along the bayous and small streams the strips are narrow and less extensive. It occupies higher elevations than other closely associated soils. The surface is almost level with a gentle recession to the "black" lands, located farther back from the stream courses.

The Yazoo soils are not subject to inundations from the rivers and bayous, due to the protecting levees, but the ground water table a large part of the year is near the surface and natural drainage is not sufficient for best results. Practically all fields are drained by open ditches placed at intervals of from 100 to 200 feet apart, with the drainage usually away from the bayous, or towards the swamps.

The areas of this type are remarkably uniform and may be illustrated by the typical profile found on Upper Ten Plantation, Raceland, La. (Fig. 2). The surface consists of a light grayish brown, light-textured, fluffy, very fine sandy loam 9 inches deep. Below this and extending to 14 inches, a light gray, compact, very fine sandy loam to silt loam layer occurs that is faintly mottled with rust brown, black, and yellow, the black colorations apparently consisting of organic matter that has come down from above through old root channels and animal burrows. The transition between these horizons is usually abrupt. The third distinct horizon, which extends to 21 inches, resembles the one above in color but has a much lighter texture which ranges from a very fine sandy loam to loamy very fine sand. Below this a light mouse gray silt loam occurs that is mottled with rust brown. This layer in turn is underlain to 30 inches by a light mouse gray very fine sandy loam, mottled in the same manner as the horizon above. The next discernible horizon is a heavy silt loam to silty clay loam, 9 inches thick, that has a color much like the one above, except that the rust brown mottles are more conspicuous. This in turn is underlain to variable depths by a gray loamy fine sand with segregated rust brown mottles and some soft black iron concretions.

Since the Yazoo very fine sandy loam is developed over an extensive area, it was considered advisable to determine the variations in the physical and chemical characteristics, if any. As might be expected in any first bottom type, variations do occur, but they are of minor importance and consist mostly of variations in the thickness and arrangement of the various layers.

In like manner the pH reaction is similar, even when some few samples of Yazoo silt loam and loam are included. For instance, if 100 samples collected from Mary Plantation, Raceland, are compared with 100 samples from Cinclare, points approximately 100 miles

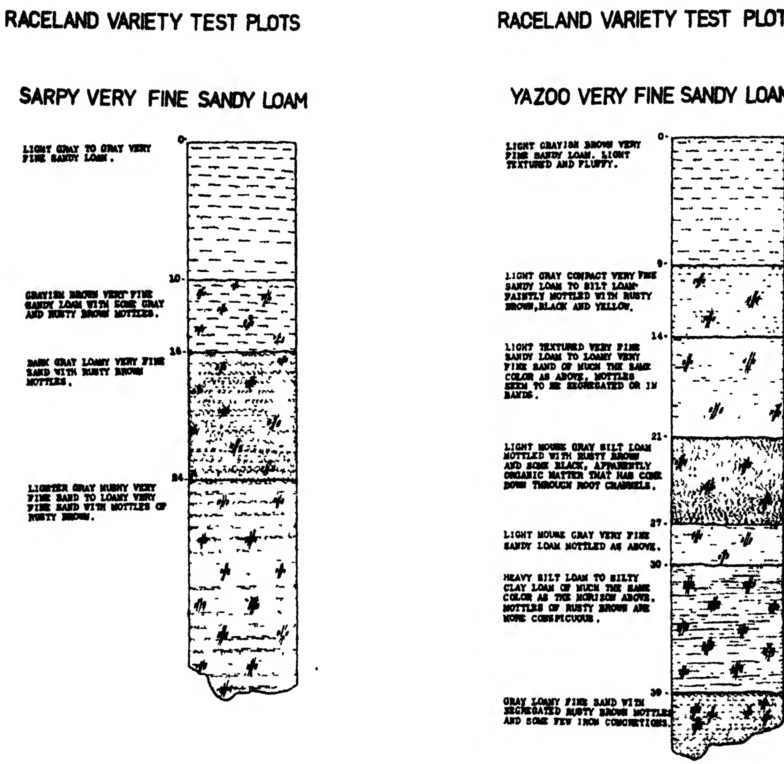

FIG. 2.—Profile of Yazoo very fine sandy loam.

apart, the range is much the same (Fig. 3). Even when 340 random samples from all parts of this soil area are compared, the curve is still very uniform.

Having determined that the Yazoo very fine sandy loam is an important sugar cane soil and that it is fairly uniform throughout the sugar cane district of Louisiana, it was considered important to determine the best methods for maintaining and improving fertility. Unquestionably, it will be necessary to carry on experiments for a number of years before this can be definitely answered, but the results of the work that has been in progress since 1929 are presented to illustrate the plan of research and the trend of the findings.

In producing sugar cane in Louisiana, every available means

should be employed to overcome the shortcomings of nature, as far as possible. Unquestionably, the short growing season demands that a well-balanced fertilizer be used that will give the maximum tonnage with greatest sugar content. It has been shown that on land where a good leguminous crop has been turned under the use of commercial fertilizers applied to plant cane has not shown returns commensurate with those from its use on first and second year stubble cane. It is generally found profitable to apply nitrogenous mixtures to all stubble crops

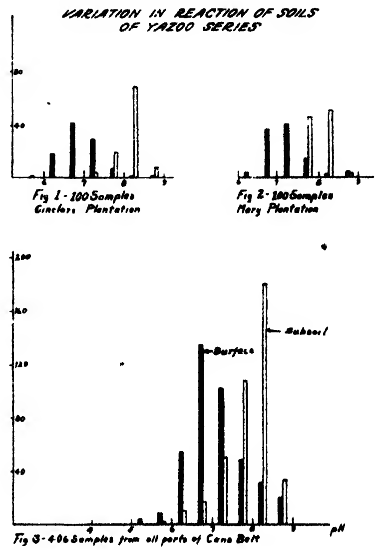

FIG. 3 The pH range of Yazoo very fine sandy loam.

Phosphoric acid and potash combined with nitrogen have given favorable returns and it may be that their residual effect is such that it is only necessary to use them once in a rotation.

The failure to use phosphoric acid and potash over a term of years, and such a theory is not without evidence, may result in considerable loss Such problems are constantly before the planters and they often ask, "What and how much fertilizer should I apply to my plant cane or stubble to get the greatest return for my money?" This can only be determined by painstaking experiments on the dominant soil types of each principal soil area. Recommendations for the Yazoo very fine sandy loam of the Mississippi Alluvium, First Bottom Soils area, will no doubt differ from those for the Yahola very fine sandy loam of the Red River area and Lintonia silt loam on the terraces, due to the differences in their origin and to their physical and chemical characteristics.

In order to secure information regarding the needs of the Yazoo very fine sandy loam under actual field conditions in Louisiana, test fields were located on Cinclare Plantation, Cinclare; Upper Ten Plantation, Raceland; Belle Terre Plantation, Donaldsonville; and Mandalay Plantation, Houma. These widely separated locations are representative of their sections.

In selecting these locations, detailed soil surveys were made to determine if the surface and subsoil characteristics were sufficiently

uniform and true to type. The distribution of the various types and series in each section was also determined. The past history of the particular tract in question was also looked into to avoid any abnormal treatment or condition. For instance, in selecting Mandalay field, a soil survey was made (Fig. 4) on a sufficiently large scale to

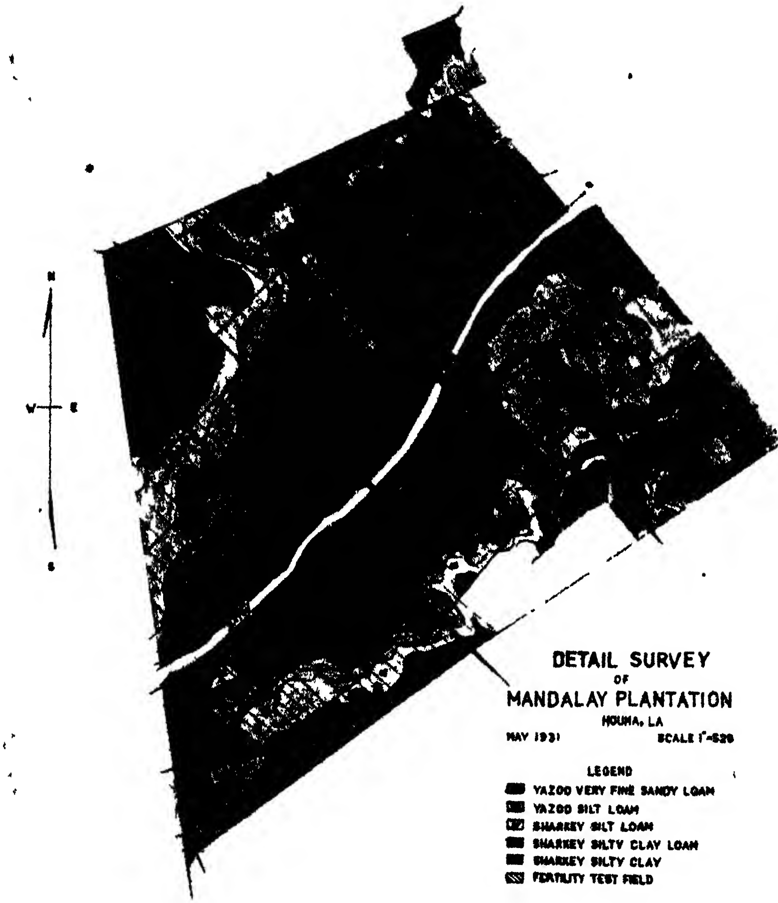

FIG. 4.—Detail survey of Mandalay plantation

permit of great detail. Next, an area of Yazoo very fine sandy loam was selected on which the desired variety of cane was being grown. Without this great care in locating fields, the intricate interlacing of soil types would introduce considerable variation.

The fertility test fields in each case were laid out so as to include

the 21 mixtures represented by the Schreiner triangle system. These 21 mixtures vary in ratios of 4% differences in combinations of the three plant food elements, nitrogen, phosphoric acid, and potash, and all fertilizer mixtures are stated in this order. These were applied at the rate of 60 pounds of total plant food per acre.

The basis of interpretation of this system is an equilateral triangle in which the extreme points represent the single elements with nitrogen (N) at the top, phosphoric acid (P_2O_5) at the left, and potash (K_2O) at the right. Each side of the triangle is divided into five equal parts and lines drawn connecting these points. It will be observed that the line forming the base of the triangle represents mixtures containing no nitrogen, whereas the sides represent mixtures free of phosphoric acid or potash. Moving from the base to the apex, each succeeding parallel line represents a 4% increase in nitrogen and the lines parallel to the sides, 4% increments of phosphoric acid or potash. In other words, the points inside the triangle represent complete mixtures. But in the case of each of the points of intersection the mixtures total 20%, but no two are alike.

As stated above, the fertility test fields were carefully selected for uniformity of soil type. But as was to be expected, the data show some variations which may be due, in part, to differences in the agronomic practises in vogue on the different plantations, or to rainfall, drainage, biological, or other factors. The experiments should therefore be extended over a period of years before definite conclusions are drawn. The trend, however, is remarkably uniform, as is shown by an analysis of the various field results.

MANDALAY FIELDS

In Fig. 5, the tons of cane and sugar per acre are given on the diagram. It will be observed that the highest yield of cane was obtained from the 12–8–0 mixture, but with nitrogen alone only 0.2 of a ton less was obtained. Below the 12% nitrogen line a steady decline in yield is noted with each 4% decrease in nitrogen. The yields along the nitrogen-phosphoric acid line, with one exception, are slightly in excess of those on the nitrogen-potash line. Check plats produced 20.8 tons.

The yield in pounds of sugar per acre gave a more definite trend. The straight nitrogen plat produced only 4,663 pounds of sugar, whereas the 12–8–0 plat produced 5,830 pounds and the 12–4–4 plat, 5,644 pounds. The 12% nitrogen line stands out as the high producer with the greatest number of high-yielding plats centered

around the 12–8–0 mixture. The low-nitrogen and nitrogen-free mixtures gave consistently low yields. The average of all checks was 3,825 pounds.

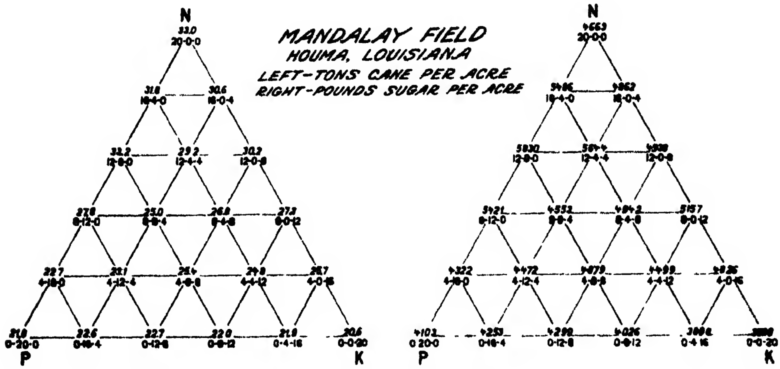

FIG. 5.—Triangle diagram showing yield of cane and of sugar per acre from different fertilizer mixtures on Mandalay field

UPPER TEN FIELD

The highest yields of sugar cane in tons per acre (Fig. 6) were produced by the high-nitrogen mixtures found in the nitrogen end of the triangle. The main center of highest yields is located at the 12–0–8 plat, though the greater number of high-yielding plats seem to group themselves more closely around the 12–4–4 plat where the yield is 2 tons less. The average yields of the nitrogen lines from base to

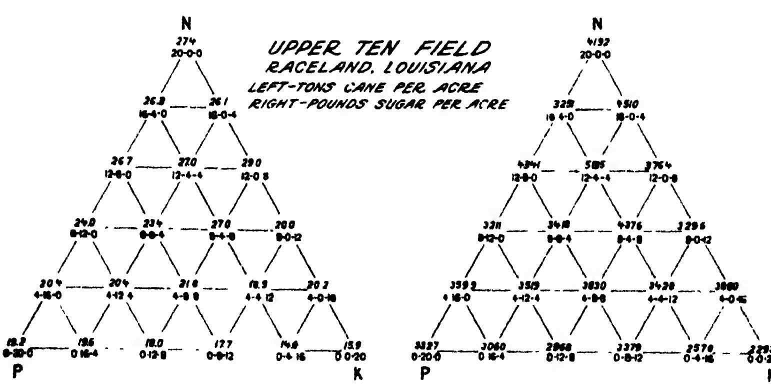

FIG. 6.—Triangle diagram showing yield of cane and of sugar per acre from different fertilizer mixtures on Upper Ten field.

apex are 17.3, 20.8, 23.8, 27.5, 26.2, and 27.4 tons. This shows a steady increase up to the 12% nitrogen line beyond which there is practically no change.

Fig. 6 also shows the yield in pounds of sugar per acre. The 12–4–4 plat stands out with the highest yield, 5,135 pounds. The 16–0–4 plat comes second with 4,510 pounds, whereas the 12–8–0 plat produced 4,341 pounds. The average of the checks was 2,891 pounds.

BELLE TERRE FIELD

The results for the Belle Terre field near Donaldsonville are shown graphically in Fig. 7. The straight nitrogen plat produced the

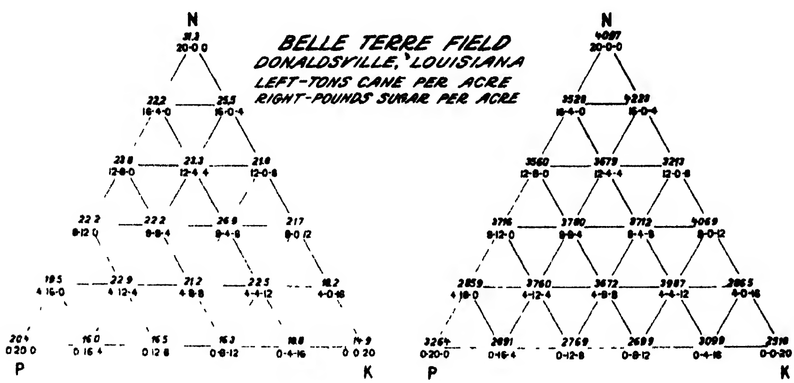

FIG. 7. Triangle diagram showing yield of cane and of sugar per acre from different fertilizer mixtures on Belle Terre field

greatest number of tons of cane per acre with the 8–4–8 plat and 16–0–4 plat following in the order named. Except for a slight increase for the 8% nitrogen line, the average yields in tons of cane per acre, moving from the apex to the base, show a steady decrease. Straight phosphoric acid shows an increase over the check, 16.6 tons, whereas straight potash showed a slight decrease.

The returns in pounds of sugar per acre shows a more definite trend. The 16–0–4 plat produced the greatest number of pounds of sugar, whereas the straight nitrogen plat dropped to second place with 4,097 pounds, or 226 pounds less. As in the case of tonnage, the sugar yield of the potash plat was less and that of the phosphoric acid plat more than the average of the checks, which was 2,706 pounds.

CINCLARE FIELD

In Fig. 8, which gives the yields in tons of cane per acre, it will be noted that all the plats on the 12% nitrogen line are consistently high. But the high yield was made by the 4–12–4 mixture and the second highest by the 0–8–12 plat, results out of line when surrounding tonnages are considered.

The yields in sugar per acre show practically the same trend. The 4–12–4 and 0–8–12 plats rank first and second, whereas most of the surrounding mixtures gave low returns. The 12% nitrogen plats,

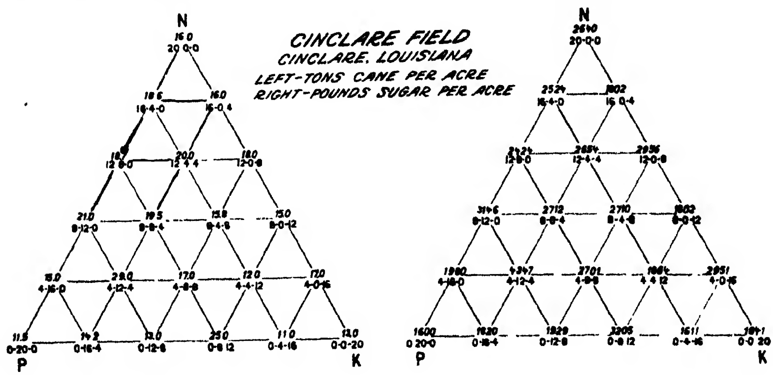

FIG. 8.—Triangle diagram showing yield of cane and of sugar per acre from different fertilizer mixtures on Cinclare field.

however, show consistently good yields. The significance of these yields is questioned due to the "gappy" stand that was caused by the presence of disease in the stubble cane.

SUMMARY

Summing up the above individual field analyses, it is interesting to note that at Mandalay, where the triangle is replicated twice, the 12–8–0 plat gave the highest yield in pounds of sugar per acre with the 12–4–4 and 16–4–0 plats following in the order named. At Upper Ten the three high-yielding plats occur in the following order, 12–4–4 plat first, 16–0–4 second, and 12–8–0 third, whereas at Belle Terre the 16–0–4 plat produced the greatest number of pounds of sugar with surrounding plats showing consistent high yields. The Cinclare field alone seems out of line when individual yields are considered, but the 12% nitrogen line shows consistently high returns.

The effect of the different fertilizer constituents on the growth of the cane is rather striking. Since such factors affect the cost of harvesting, they should be taken into consideration when selecting the best fertilizer for use on the plantation. For instance, in Fig. 9, it will be noticed that the P. O. J. 213 cane from the 12–4–4 plat is comparatively straight, while that from the nitrogen plat is crooked. The differences in the percentage of lodging were more marked in the field. The same differences were observed in the check plats and in the 4–16–0, 12–8–0, and 20–0–0 plats. In a comparison of P. O. J. 213 cane from check, 8–4–8, 12–4–4, and 16–4–0 plats, it is

FIG. 9.—Effect of nitrogen alone and certain mixtures on erectness of cane.

significant that there was very little lodging, even for the 16-4-0 mixture. The increase in the length of millable cane in all cases was rather striking. It was also observed that the increase was in direct proportion to the amount of nitrogen up to the 12% mixture beyond which there was practically no improvement. The 12-4-4 mixture, it would seem, produced the most satisfactory cane showing an average length of 5 3/4 feet of millable stalk.

EFFECTS OF FERTILIZERS ON THE SEASONAL PRODUCTION OF PASTURES[1]

B. A. Brown[2]

There are many carefully obtained data to support the common observation that hay and pasture plants make most of their annual growth early in the season In fact, the luxuriance of pastures in June has long been a by-word. The uneven seasonal production of permanent pastures may be more readily appreciated if it is stated that, in general, grasses make about two-thirds of their annual growth in the first third of the season Although the dates when the several species start growth in the spring or reach the period of greatest production vary considerably, there is not enough difference between them to affect importantly this common situation Therefore, when in recent years, many trials demonstrated the marked effects of fertilizers in increasing the *total* yields of pastures, particularly pastures of the run out, permanent type, many also hoped a more uniform production could be obtained by proper fertilization. In respect to this important factor in pasture economy, this paper gives the results obtained during the past 5 years at the Storrs (Connecticut) Agricultural Experiment Station

PLAN OF EXPERIMENT

The project in question was started in 1921 on a run down, brush-grown, permanent pasture The soil is a sandy loam, with a compact subsoil, and is quite retentive of moisture Locally, it is considered good "grassland." The brush was removed and nine 4-acre plots were laid out and fenced on the area. After 3 years of preliminary grazing without treatment of any kind, each plot was fertilized differently in 1924. In most instances the mineral applications of 1924 were repeated in 1929 and nitrogenous fertilizers have been applied annually to some plots since 1926. These experimental

[1]Contribution from Department of Agronomy, Storrs (Conn.) Agricultural Experiment Station, Storrs, Conn. Received for publication March 21, 1932

[2]Associate Agronomist.

pastures have been grazed with yearling steers, which are weighed at approximately 2-week intervals. As the feed in each pasture has been grazed at approximately the time it grew, considerable data bearing on the effects of various methods of fertilizing pastures on their seasonal production have accumulated. Those interested in further information in regard to methods employed in conducting this experiment and in calculating the results are referred to Bulletin 155 of the Storrs Experiment Station.

The following symbols will be used to designate fertilizer treatments: L, limestone at 1 ton in 1924 and 1929; P, superphosphate (16%) at 500 pounds in 1924 and 1929; K, muriate of potash at 100 pounds in 1924 and 1929; N, nitrogen at 28 pounds annually in April; NN, nitrogen at 56 pounds annually in April; and NN[1], nitrogen at 56 pounds annually, one-half in April and one-half in July.

Because nitrogen was not applied annually before 1927, the data for the preceding years will not be given here. Moreover, due to the negligible effects of potash on the character of growth and the yields of these pastures and to the great similarity in these respects between the unfertilized and the LK plots and the limed and unlimed nitrogen plots, the results are grouped as follows: No treatment and LK; P and PK; PL and PLK; and PKN, PKLNN, and PKLNN[1] Also, the data have been condensed further by combining the results from two or more of the approximately 2-week grazing periods

The four general periods for which data are tabulated are as follows· (1) Before May 15, a period when many permanent pastures in northeastern United States afford so little grazing that milking cows are seldom expected to obtain much of their daily ration outside the barn. (2) May 15 to June 15, a time of maximum production and frequently termed the "zenith" period. The common pasture grasses, Kentucky bluegrass and sweet vernal, bloom during this period· usually in early June in Connecticut. Rhode Island Bent flowers about 3 weeks later (3) June 15 to July 15, a period characterized by a greatly reduced growth of most pasture species and, if rainfall is deficient, by a "drying up" or "browning" of the turf. (4) After July 15, a long period comprising over 50% of the possible pasture season in this region and marked by a general dearth of good grazing, except that furnished by the aftermath in meadows during seasons when the amount of rainfall is average or above and well distributed. However, where moisture is ample, good bluegrass pastures usually make some growth after August 15. This long period of scanty pasturage is a great problem to livestock farmers.

Aftermath, soiling and silage crops, hay, grain, and, more recently, emergency or annual crops for pasture have all been used to supply feed during the three months in question.

RESULTS FOR 1927-31

For the four periods just discussed, the actual units of feed produced on the variously fertilized pastures and the respective percentages of the season's total production, as measured by the number of steers maintained and their gains in weight for 1927-31, inclusive, are given in Tables 1 and 2. The 5-year averages are shown graphically in Fig. 1.

The production of permanent pastures is influenced so much by the amount and distribution of the rainfall that the monthly precipitation during the five growing seasons under discussion are given below:

Rainfall at Storrs during growing seasons of 1927-31.

Year	May	June	July	August	September	Total
1927	3.95	2.50	4.11	6.26	0.96	17.78
1928	1.24	4.43	6.78	5.71	2.60	20.76
1929	5.13	2.09	1.03	2.32	0.94	11.51
1930	2.92	2.58	3.49	1.90	0.58	11 47
1931	4.08	5.79	2.45	4.37	1.68	18.37
42-year average	3.46	2.99	4.40	3.86	3.66	18.37

It may be noted that 1927 had approximately normal rainfall in every month except August, which was very wet, and September, an extremely dry month. In 1928 it was very dry during May, very wet in June, July, and August, and rather dry in September. All months of both 1929 and 1930, except May of the former year, were dry to extremely dry, the total rainfall for the 5 months being less than two-thirds of the 42-year average. On the whole, 1931 was a relatively normal season, although the rainfall for June was about 90% above the average, while July was 35% and September over 50% below the average. Thus, so far as the important late summer period is concerned, it might be said that two years (1927 and 1928) were very wet, two (1929 and 1930) very dry, and one (1931) about average. Due to the excessive evaporation in July and August, an average amount precipitation in those months is seldom sufficient for a good growth of the common pasture grasses. Of course, the distribution and character of the storms and the proportion of clear days influences markedly the efficiency of low to moderate amounts of rainfall.

A study of the data in Table 1 shows that there is, as might be expected from the nature of the experiment, a considerable variation

from year to year in both the actual and proportional amounts of feed produced during any given period. For instance, the percentages of the total season's production obtained before May 15 in 1930 were high for all treatments. This was due primarily to two causes, *viz.*, (1) an early spring permitted the beginning of grazing on April 29, the earliest during the 11 years this experiment has been conducted; and (2) an extremely dry August and September resulted in very little grazing after August 1. Another example of the marked influence of the rainfall is furnished by the unusually large amounts of feed produced after July 15 in 1928, a season characterized by rainfall 50% above the average in July and August. During that season the unfertilized plot produced more feed than in any of the other 11 years.

TABLE 1.—*Effects of fertilizers on the seasonal production of permanent pastures as measured by feed units per acre.*

Fertilization of plots averaged*	Feed units in therms					
	1927	1928	1929	1930	1931	Average
			Before May 15			
None and LK	43	19	33	45	0	28
P and PK	87	29	74	182	85	91
PL and PKL	119	45	112	285	113	135
PKN and PKLN	133	78	161	469	268	222
			May 15–June 15			
None and LK	140	172	201	253	203	194
P and PK	316	306	412	221	333	318
PL and PKL	367	445	603	286	444	429
PKN and PKLN	446	567	865	386	744	602
			June 15–July 15			
None and LK	233	194	176	210	258	214
P and PK	334	435	365	358	261	351
PL and PKL	480	380	498	557	365	456
PKN and PKLN	469	504	506	471	389	468
			After July 15			
None and LK	393	647	213	98	183	307
P and PK	490	678	271	160	402	400
PL and PKL	621	563	363	233	559	468
PKN and PKLN	560	708	153	213	608	448
			Totals for Season			
None and LK	809	1,032	623	606	644	743
P and PK	1,227	1,448	1,122	921	1,081	1,160
PL and PKL	1,587	1,433	1,576	1,361	1,481	1,488
PKN and PKLN	1,608	1,857	1,685	1,539	2,009	1,740

*L = limestone at 1 ton in 1924 and 1929; P = superphosphate (16%) at 500 pounds in 1924 and 1929; K = muriate of potash at 100 pounds in 1924 and 1929; N = 28 pounds of nitrogen per acre annually from sulfate of ammonia and nitrate of soda. The PKLN plots received 56 pounds of nitrogen in 1929, 1930, and 1931; all in April on one plot, and one-half in April and one-half in July on the other.

TABLE 2.—*Effects of fertilizers on the seasonal production of permanent pastures in terms of feed units as percentage of total.*

Fertilization of plots averaged*	Feed units in therms as percentage of total					
	1927	1928	1929	1930	1931	Average
			Before May 15			
None and LK	5.6	1.8	5.7	6.7	0.0	4.0
P and PK	7.1	2.3	6.8	19.4	8.0	8.7
PL and PKL	7.5	3.2	7.1	21.0	7.5	9.2
PKN and PKLN	8.2	4.3	9.5	30.4	13.2	13.1
			May 15 June 15			
None and LK	17.3	16.6	32.6	42.4	31.7	28.1
P and PK	25.7	23.4	37.0	24.1	31.5	28.3
PL and PKL	23.2	31.5	38.4	21.1	30.1	28.9
PKN and PKLN	27.6	31.3	51.3	25.0	37.2	34.5
			June 15-July 15			
None and LK	28.4	18.7	28.1	35.5	40.4	30.2
P and PK	27.1	22.7	33.0	39.0	24.6	29.3
PL and PKL	30.4	26.5	31.6	41.0	25.0	30.9
PKN and PKLN	30.0	27.8	30.6	30.6	19.0	27.6
			After July 15			
None and LK	48.7	62.9	33.6	15.4	27.9	37 7
P and PK	40.1	51.6	23.2	17.5	35.9	33.7
PL and PKL	38.9	38.8	22.9	16.9	37.4	31.0
PKN and PKLN	34 2	36.6	8.6	14.0	30.6	24.8

*L = limestone at 1 ton in 1924 and 1929; P = superphosphate (16%) at 500 pounds in 1924 amd 1929; K = muriate of potash at 100 pounds in 1924 and 1929; N = 28 pounds of nitrogen per acre annually from sulfate of ammonia and nitrate of soda. The PKLN plots received 56 pounds of nitrogen in 1929, 1930, and 1931; all in April on one plot, and one-half in April and one-half in July on the other

The common occurrence of periods with unfavorable weather conditions and their marked effects on permanent pasture production makes it inadvisable to draw any conclusions from the results of 1 or even 2 years. Therefore, the discussion will be confined chiefly to the 5-year averages. These averages show that the fertilizers containing nitrogen produced appreciably more feed, both actually and proportionately, before May 15 and from May 15 to June 15 than any of the other treatments. The largest actual difference in favor of nitrogen is in the zenith period (May 15 to June 15). After June 15, the complete mineral (LP and LPK) treatments produced practically the same amount of feed as those with nitrogen.

In actual production, the "no phosphorus" plots (no treatment and LK) were considerably below the others in all periods, but produced a slightly greater proportion of the feed during the late summer and fall months. In other words, the plots not receiving the most important (for this soil) plant nutrient—phosphorus—had a more even production than any of the others. However, the herbage on the "no

phosphorus" plots contains a large percentage of wild oat grass (*Danthonia spicata* L.), a species far less palatable and nutritious than the blue and bent grasses which predominate on the phosphorus plots.

The average of the P and PK plots is about midway between those with no phosphorus and PL and PLK in actual feed production, but are practically the same as the latter in respect to the proportion of the total production available for grazing each period.

If the results for all treatments are averaged, it is found that the percentages of the total feed produced in the various periods were as follows:

Period	Percentage of total production*	Treatments with extreme percentages	
		Lowest	Highest
Before May 15	9	No P (4%)	PKLN (13%)
May 15–June 15	30	No P (28.1%)	PKLN (34.5%)
June 15–July 15	29	PKLN (27.6%)	PKL (30.9%)
July 15–Oct. 15	32	PKLN (24.8%)	No P (37.7%)

*Average of all data in Table

It is apparent that 68% of the total feed was produced before July 15 and only 32% during the three or more months of grazing possible in this region after that date. These 5-year averages, based on thermal production, are in substantial agreement with the seasonal gains in weight by the steers for the first 8 years the experiment was conducted. For that 8-year period 62% of the gains on all plots were made before July 1 and 86% before August 1.[3] Moreover, the seasonal production curves for the nitrogen plots, shown in Fig. 1, are very similar to the graphs based on the yields of dry matter of monthly cut plots at Cambridge, England, published recently by Woodman and Underwood.[4]

TIME OF APPLYING NITROGEN

In recent years, much has been said about the effects of frequent applications of nitrogen on maintaining the late season carrying capacity of pastures. In fact, this practice has been considered one of the main factors in the Hohenheim system of pasture management. For the purpose of obtaining some data on the effects of summer applications of nitrogen, one plot in the Storrs project has been given one-half of the total nitrogen in July. An adjacent

[3]Storrs Experiment Station Bulletin 155, p. 161. 1929.

[4]WOODMAN, H. E., and UNDERWOOD, E. J. The nutritive value of pasture. VIII. The influence of intensive fertilizing on the yield and composition of good permanent pasture (seasons 1 and 2). Jour. Agr. Sci., 22: 26–71. 1932.

plot has received all of the nitrogen (56 pounds per acre) in April. In both cases, 72% of the nitrogen was obtained from sulfate of ammonia and 28% from nitrate of soda. The average dates of apply-

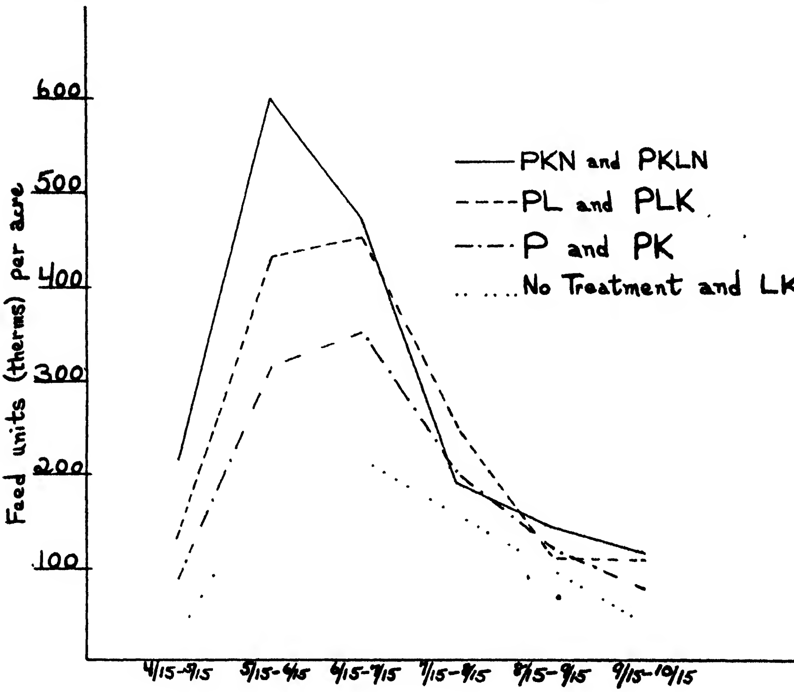

FIG. 1.—Seasonal production of pastures. Average results at the Storrs Agricultural Experiment Station, 1927–31.

ing the nitrogen have been April 15 and July 10. Approximately a month's rest has been given both plots after the July application of nitrogen. Also, in 1930 and 1931, each plot had a rest period of 2 to 3 weeks in June. Since 1923, limestone at 2 tons, 16% superphosphate at 1,000 pounds, and muriate of potash at 200 pounds per acre have been applied to both plots. The effects of these treatments have now been measured by grazing for 3 years, *viz.*, 1929, 1930, and 1931, and the results are given in Tables 3 and 4 and graphically in Fig. 2.

Applying one-half of the nitrogen in July has resulted in decreasing the *total* production about 10% in 1929 and in 1931 and increasing it about 5% in 1930. The actual and proportional productions for each period, except after July 15, were practically always greater where all of the nitrogen was applied in April. On the other hand, the amounts of feed for the period *after* July 15 were greater in all cases where one-half of the nitrogen was applied in July. In this respect,

TABLE 3.—*Effects of dividing the nitrogen treatment on the seasonal production of pastures as measured by grazing.*

Time of applying nitrogen*	Feed units in therms per acre			
	1929	1930	1931	Average
Before May 15				
All in April	194	517	361	357
One-half in July	178	496	238	304
May 15–June 15				
All in April	1,024	373	758	718
One-half in July	876	323	741	647
June 15–July 15				
All in April	468	437	635	513
One-half in July	412	422	381	405
After July 15				
All in April	214	166	421	267
One-half in July	234	324	604	387
Total for Season				
All in April	1,900	1,493	2,175	1,856
One-half in July	1,700	1,565	1,964	1,743

*56 pounds of nitrogen per acre in either case. 72% of the nitrogen was from sulfate of ammonia and 28% from nitrate of soda.

TABLE 4.—*Effects of dividing the nitrogen treatment on the seasonal production as percentage of the total.*

Time of applying nitrogen*	Feed units in therms per acre			
	1929	1930	1931	Average
Before May 15				
All in April	10.2	34.6	16.6	20.5
One-half in July	10.5	31.7	12.1	18.1
May 15–June 15				
All in April	53.9	25.0	34.9	37.9
One-half in July	51.6	20.6	37.7	36.6
June 15–July 15				
All in April	24.6	29.2	29.2	27.7
One-half in July	24.2	26.9	19.4	23.5
After July 15				
All in April	11.3	11.2	19.3	13.9
One-half in July	13.7	20.8	30.8	21.8

*56 pounds of nitrogen per acre in either case. 72% of the nitrogen was from sulfate of ammonia and 28% from nitrate of soda.

the largest differehce was 183 feed units (therms) per acre, or about 10% of a total season's production on a well-fertilized plot. This difference is much less than that caused by the varying amounts of

rainfall during July and August of the 3 years in question. The greatest *proportion* of the *total* feed obtained after July 15 from the divided application of nitrogen was 30.8% in 1931, a season with

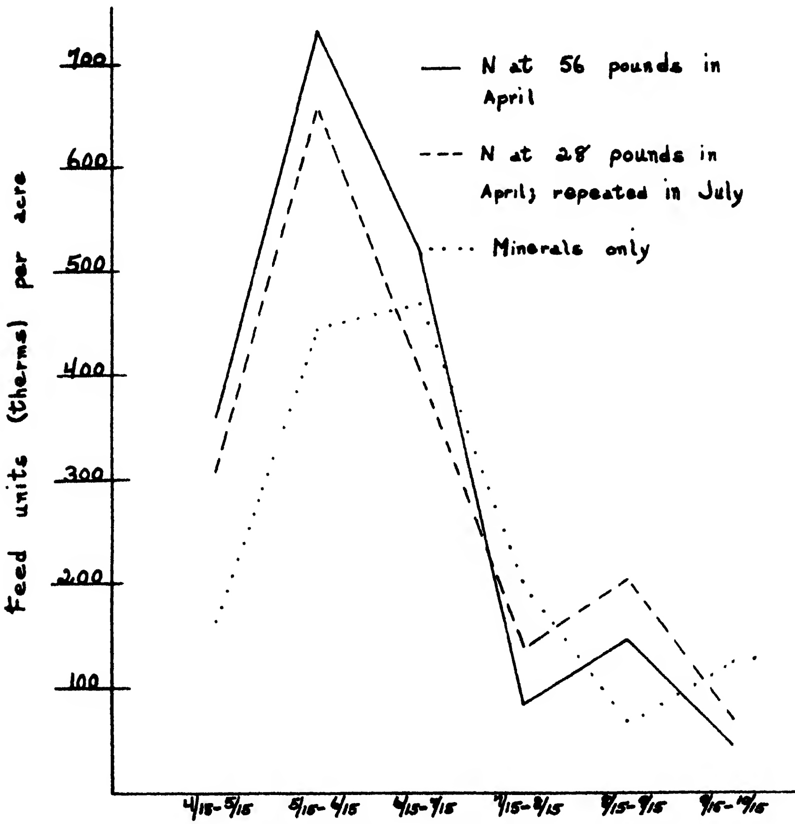

FIG. 2.—Seasonal production of pastures. Average results at the Storrs Agricultural Experiment Station, 1929–31.

above average rainfall in June and August. However, even in this favorable season, the actual production after July 15 was only 49 feed units (therms), or 8% greater where both April and July applications of nitrogen were given than for the complete mineral plots receiving no fertilizer nitrogen.

In the same season, the complete mineral plots produced 138 therms (over 30%) more feed after July 15 than the plot given 56 pounds of nitrogen in April. Of the relatively well-fertilized plots in this project, the one receiving the largest amount of nitrogen in April has presented the poorest appearance in July and August. The causes of this condition have not been determined. In view of

Graber's work with grasses in Wisconsin,[5] one might surmise that the high production made possible by the favorable weather conditions early in the season and by the large supply of fertilizer nitrogen, coupled with rather early and almost constant grazing in May and June, had exhausted the food reserves in the roots of the grasses. At least this plot has required a long period for recuperation.

LATE SEASON GRAZING

In general, the results from any of the methods of fertilization tried at Storrs have been disappointing in solving the problem of providing adequate amounts of grazing for the latter half of the season. Withholding all fertilizer nitrogen until after the zenith period has passed, or until the natural late summer growth of grasses occurs, may give better results. Plots with such treatments will be included in the project during the next few years. However, judging from some data obtained, resting pastures from the end of the zenith period until August is a more important factor in securing late summer grazing than is the mid-season applications of nitrogen. In regard to this point, the following data were secured in 1931 from a few differently managed plots:

Fertilization	Rest period	Feed units in therms obtained			
		Total	Before July 15	After July 15	Percentage of total after July 15
Minerals only	June 30–July 31	1,601	881	720	45
Minerals only	July 22–Aug. 14	1,404	926	478	34
Nitrogen in April	June 30–July 31	1,949	1,245	704	36
Nitrogen in April and July	July 15–Aug. 14	1,963	1,359	604	31

These results indicate that a rest period starting soon after the last flowering date of the pasture grasses will help appreciably in providing more late summer grazing. In Connecticut, if this period begins much before the latter part of June, many flower stalks and less leafy growth will be produced during the remainder of the season. However, different pastures in the same locality might be grazed at considerably different times with satisfactory results. For example, a pasture with bluegrass or orchard grass could be rested earlier in the season than one containing the later flowering bent grasses or ordinary timothy.

[5] GRABER, L. F. Food reserves in relation to other factors limiting the growth of grasses. Plant Phy., 6: 43–72. 1931.

SUMMARY

This paper reports the effects of various fertilizer treatments on the seasonal production of permanent pastures for 5 years at the Storrs (Connecticut) Agricultural Experiment Station.

Although the *total* production has been greatly increased by fertilization, none of the treatments has affected very markedly the *proportion* of the *total* feed produced in a given part of the season.

During the 5-year period of 1927–31, the mineral plus nitrogen plots produced 252 feed units (17%) per acre per year more than the plots receiving minerals only. Of this difference in favor of nitrogen, over two-thirds was produced during the zenith period, May 15–June 15, and the remainder before May 15.

In regard to the period *after July 15*, a time when pastures are much less productive, the plots receiving minerals and nitrogen have produced less, both actually and proportionately, than those receiving minerals only

Applying one-half of the nitrogen in July rather than all in April has resulted in slightly less *total* feed but in about 8% more grazing during the late summer months

Of the well-fertilized plots, the one receiving the largest amount of nitrogen in April has presented the poorest appearance in July and August.

In 1931, the average production of all pastures *after July 15* was 30% of the total By resting a complete mineral (no nitrogen) plot from June 30 to July 31, the corresponding percentage was increased to 45, and more feed was obtained in late summer than from *any* of the other pastures, indicating that management may be a more important factor in solving this problem than the frequent applications of nitrogen

SOME CORRELATIONS BETWEEN CROP YIELDS AND THE READILY AVAILABLE PHOSPHORUS IN SOILS AS DETERMINED BY TRUOG'S METHOD[1]

Franklin L. Davis and George D. Scarseth[2]

Various methods for determining the relative amount of phosphorus in soils that is available to plants have been published in the last few years. The objective of these methods is the determination of a relative value for the amount of readily available phosphorus in soils which would be an accurate index of the soil's supply of phosphorus that is available and effective for plant or crop growth. This value should be closely indicative of the soil's phosphorus fertility level and of the soil's needs for phosphorus fertilization. If this objective is attained in the individual method, the values for readily available phosphorus obtained by it would be accurate indexes of the crop-producing capacity of the soils in regard to phosphorus, and should be closely related to the yield of crops on these soils when they are supplied with all the other major fertilizing elements. With these conditions, phosphorus should be the limiting fertility factor.

During the course of the laboratory and greenhouse investigations conducted on the major soil types of Alabama, the readily available phosphorus by Truog's method[3] has been determined on a number of soils, and the correlations between the values obtained and the yield of some crops on these soils have been calculated. In view of the rather general application that is being made of the several methods of determining values for the relative amount of phosphorus in soils that is available and effective in crop growth, the correlations that have been noted on Alabama soils are herein reported.

BLACK BELT SOILS

In a special study of the major soil types of the Black Belt of Alabama,[4] a number of soils were tested in the greenhouse to deter-

[1]Contribution from the Department of Agronomy and Soils, Alabama Polytechnic Institute, Auburn, Ala. Paper presented at the Thirty-third Annual Convention of the Association of Southern Agricultural Workers held in Birmingham, Alabama, February 2, 3, and 4, 1932. Published with the approval of the Director of the Alabama Agricultural Experiment Station. Received for publication March 25, 1932.

[2]Assistant Soil Chemists.

[3]Truog, E. The determination of the readily available phosphorus in soils. Jour. Amer. Soc. Agron., 22: 874–882. 1930.

[4]Scarseth, Geo. D. Morphological, greenhouse, and laboratory studies of the Black Belt soils of Alabama. Ala. Agr. Exp. Sta. Bul. 236. 1932.

mine their responses to fertilizers. Approximately 500 pounds of each of the samples were collected in the field from representative areas in which their respective types occur. In the greenhouse these samples were screened to remove the coarser gravel and stones and all plant debris, and were thoroughly mixed. From the soils thus prepared 9-kilogram samples were weighed and transferred into 2-gallon glazed pots. These pot cultures of each of the soils were fertilized and planted simultaneously to oats.

The pot cultures included fertilizer treatments in duplicate of (1) nitrogen alone; (2) nitrogen and potassium; (3) nitrogen, phosphorus, and potassium; and (4) other treatments. Only the yields of the nitrogen and potassium and the nitrogen, phosphorus, and potassium treatments are considered here. The average yields of oats on the duplicate pot cultures of these treatments are given in Table 1. This table also gives the relative value for the yield made without phosphorus in percentage of the yield made where phosphorus was applied, the amount of readily available phosphorus by the Truog method, and the total phosphorus in the soils.

TABLE 1.—*Total P_2O_5, available PO_4, and yield of oats in pot cultures of 22 Black Belt soil types.*

Soil No.	Soil type	Total P_2O_5 per acre, lbs.	Available PO_4 per acre (Truog's method), lbs.	Yield of oats with N and K treatment, grams	Yield of oats with NPK treatment, grams	$\frac{\text{NK yield} \times 100}{\text{NPK yield}}$ %
732	Sumter Clay...	404	4.6	3.8	43.7	8.7
690	Houston Clay..	1,718	7.5	0.8	22.1	3.6
689	Sumter Clay...	2,163	10.7	4.0	44.8	8.9
738	Eutaw Clay....	1,680	11.5	2.9	62.2	4.6
694	Oktibbeha Clay	1,181	11.6	0.8	14.7	5.4
744	Oktibbeha Clay	1,338	12.0	1.5	29.0	5.1
741	Eutaw Clay..	1,480	14.6	1.8	50.7	3.5
693	Eutaw Clay....	1,728	15.2	0.3	55.6	0.5
737	Sumter Clay....	4,530	15.2	4.9	48.7	10.0
745	Sumter Clay ...	8,825	17.3	12.3	56.0	21.9
736	Oktibbeha Clay	3,120	21.6	5.5	51.3	10.7
688	Sumter Clay....	5,006	25.6	4.5	34.8	12.9
734	Sumter Clay....	12,180	29.6	9.5	52.8	17.9
742	Lufkin Clay....	3,432	30.2	12.6	63.4	19.9
733	Oktibbeha Clay	1,910	31.2	47.2	63.6	74.0
687	Oktibbeha Clay	1,542	32.2	2.8	50.3	5.5
691	Houston Clay..	2,364	43.0	3.8	48.6	7.8
639	Houston Clay..	2,341	64.4	33.9	77.1	43.8
692	Leaf Clay......	1,760	69.6	29.2	52.7	55.4
735	Oktibbeha Clay	1,467	80.2	35.7	59.8	59.6
743	Lufkin Clay....	3,829	95.2	53.4	67.3	79.3
740	Bell Clay......	13,180	144.0	66.7	82.3	81.0
Mean		3,508	33.26	15.67	51.58	30.40

No discussion of the total P_2O_5 content is necessary, except to mention that these soils vary greatly in their total phosphorus content. The fact that several of these soil types are residual from a calcareous marine deposit of biological origin may account for such high values as 12,180 and 13,180 pounds of P_2O_5 per acre in soils 734 and 740, respectively.

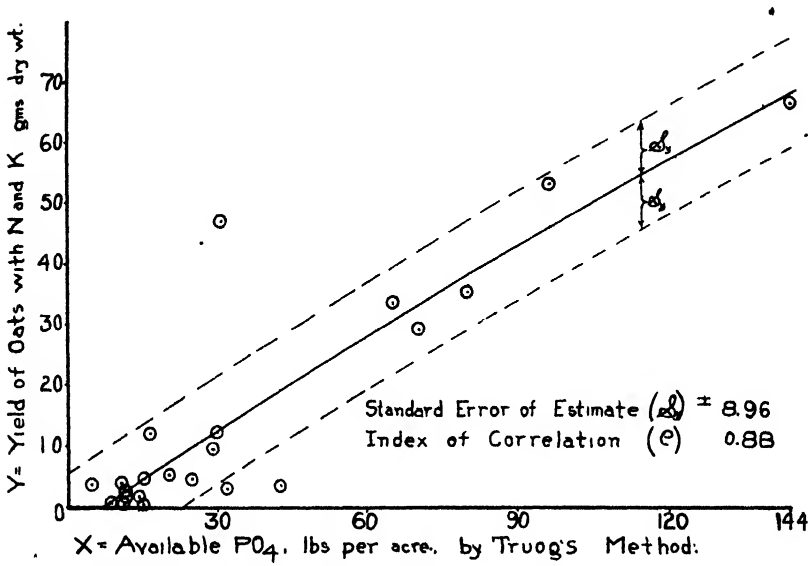

FIG. 1.—Relationship between the amount of readily available phosphorus and the yield of oats on 22 Black Belt soils.

It will be noted that the yields of oats, when fertilized with only nitrogen and potassium, were very low on the majority of the soils. The minimum yield in dry matter was 0.3 gram and the maximum yield 66.9 grams.

Fig. 1 shows the amount of readily available PO_4 plotted against the yields of oats produced with nitrogen and potassium fertilization. A second degree parabola was fitted to these data by the method of least squares. The type equation for this curve is as follows: $Y=a+bX+cX^2$. In the graph the amount of readily available PO_4 is the independent variable (X) and the yield of oats the dependent variable (Y). The equation for the most probable curve fitting these data is $Yc=-3.156+0.718X-0.000{,}480\ X^2$. Yc is the value of the crop yield along the line of relationship.

It was found that the index of correlation (ρ), evaluating the relationship existing between the content of readily available PO_4

and the yield of oats, is +0.884. The standard error of estimate is ±8.96 and its first zone is shown on the graph in broken lines.

It may be noted that the positions for most of the soils on the graph are near the lower end of the curve. The distribution of the points is such that the curve does not bend back normally within the limits of the graphed values of X and Y. With a distribution of values for X and Y, in which more of the points should be located near the upper portion of the curve, a more nearly normal curve would be expected.

In the case of the data presented, 70 grams of oats, which represented a maximum growth, were produced on soils containing 150 pounds per acre of readily available PO_4. With one exception less than one-third of the maximum growth was obtained on soils containing less than 45 pounds per acre of readily available PO_4.

NORFOLK SANDY LOAMS

For the laboratory and greenhouse investigations of the Norfolk sandy loams, each of 22 representative samples of typical Norfolk soils were collected[5] in the field from the main areas in which the Norfolk fine sandy loams and sandy loams occur throughout the entire Coastal Plain of the state. Sub-soil samples of three of the soils were taken. In the greenhouse, pot cultures of these samples were prepared in a manner similar to the procedure previously described for the Black Belt soils. Three consecutive crops were grown on these pot cultures. The first crop was Austrian winter peas. After the Austrian winter peas were harvested the soils were removed from the pots. All roots were carefully removed from the soils by screening. The soil from each pot was re-fertilized, thoroughly mixed, repotted, and planted to sorghum. Similarly, a second crop of sorghum was grown on each soil. The fertilizer treatments for the pot cultures were similar to those for the Black Belt soils.

The average yields of the duplicates of the first crop of sorghum on each of the 25 soils are given in Table 2. Along with these yields are given the values of the readily available phosphate as determined by Truog's method and as determined by a slight modification of Truog's method. The variation from Truog's method in this modification consisted only of allowing the soil sample being extracted to stand overnight, or 16 hours, in contact with the extracting solution before filtration.

[5]J. F. Stroud, Chief Soil Surveyor, cooperated in the collection of the Norfolk and Greenville soil samples.

It will be noted in Table 2 that the content of total phosphoric acid is uniformly low in the Norfolk soils. They range from 261 to 916 pounds of P_2O_5 per acre with an average of 507.4 pounds. The readily available phosphorus by Truog's method ranges from

TABLE 2.—*Total P_2O_5, available PO_4, and yield of sorghum in pot cultures of 25 Norfolk sandy loams.*

Soil No.	Total P_2O_5* in lbs., per acre	Available PO_4 in lbs. per acre		Yield of sorghum* with N and K treatment, grams	Yield of sorghum* with NPK treatment, grams	NK yield x 100 / NPK yield %
		Truog's method	Truog's method modified			
791-B	424	12.5	18.5	0.5	6.8	7.4
790-B	366	15.8	18.7	0.3	3.5	8.6
777	261	16.4	21.5	1.7	25.6	6.6
784	322	19.6	21.5	0.5	27.2	1.8
790-A	458	19.6	26.6	1.0	27.6	3.6
781	362	21.1	31.0	4.0	31.3	12.8
782	382	23.8	46.4	12.7	28.2	45.0
780	603	26.4	53.0	5.7	19.3	29.5
779	442	11.6	53.3	6.4	33.6	19.0
785	523	30.2	55.3	8.3	29.0	28.6
788	382	28.5	57.4	10.4	25.2	41.3
792	572	32.6	64.0	9.9	36.4	27.2
789	458	27.2	65.0	13.3	31.5	42.2
786	523	53.2	75.3	11.0	34.4	32.0
776	733	49.5	111.3	4.6	13.9	33.1
793	733	48.6	113.4	3.4	14.6	23.3
783	563	41.2	115.1	22.4	37.0	60.5
795	893	46.7	116.8	21.5	33.4	64.4
787	583	53.4	129.0	18.1	27.9	64.9
774	916	115.9	147.7	15.7	24.1	65.1
775	779	126.5	173.0	2.7	7.4	36.5
794	779	63.2	179.0	29.0	34.0	85.3
778	623	131.9	200.2	22.6	40.2	56.2
791-A	733	70.6	215.6	27.0	34.5	78.3
790-A	847	162.1	312.4	34.7	40.1	86.5
Average	570.4	49.93	97.01	11.5	26.67	43.11

*Data by W. W. Pate, formerly Assistant Soil Chemist in charge of the project

11.6 to 162.1 pounds of PO_4 per acre with an average of 49.93 pounds. By the modification of Truog's method, the readily available phosphorus ranges from 18.5 to 312.4 pounds of PO_4 per acre with an average of 97.01 pounds. By the modification of the method an average of almost twice as many pounds of available PO_4 per acre was obtained, as well as a different ranking of the soils in regard to their readily available PO_4 content. This resulted in a difference in the degree of correlation between the yield of sorghum and the amount of readily available phosphorus obtained by the two methods.

It will be further noted in Table 2 that the increase in yields obtained by fertilizing with phosphorus, nitrogen, and potassium over fertilizing with nitrogen and potassium shows a good general

correlation with the amount of readily available phosphorus obtained by the modification of Truog's method. The yields without phosphorus fertilization on those soils which contained less than 115 pounds per acre of readily available PO_4 in no case exceeded 50% of their corresponding yields when fertilized with phosphorus.

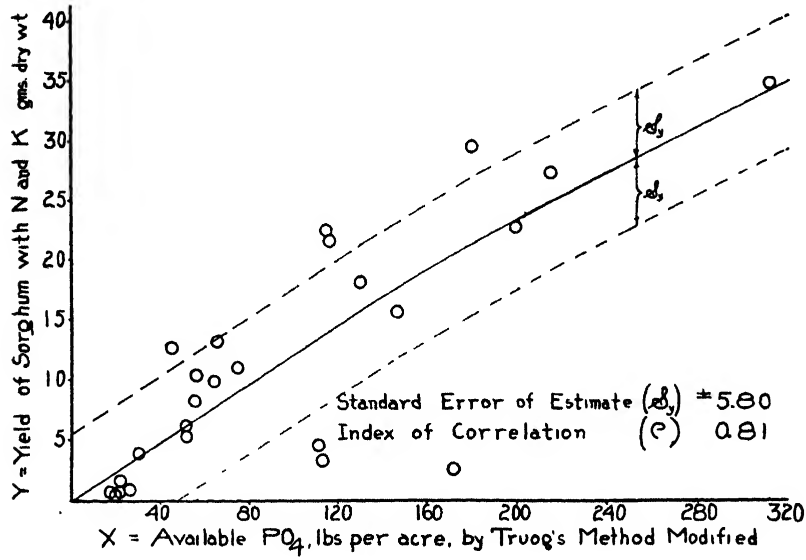

FIG. 2.—The relationship between the amount of readily available phosphorus as determined by Truog's method modified and the yield of sorghum on 25 Norfolk sandy loams.

The yields without phosphorus fertilization on those soils which contained more than 115 pounds per acre of readily available PO_4 were more than 50% of their corresponding yields when fertilized with phosphorus in every case except one.

In Fig. 2, the amounts of readily available phosphorus obtained by the modification of Truog's method and the yields of the first crop of sorghum when fertilized with nitrogen and potassium have been plotted and the second degree parabola curve has been fitted to the data by the method of least squares.

The equation for the most probable line fitting these data is $Yc = -0.034 + 0.124,600X - 0.000,051\ X^2$.

This equation expresses the relationship of the yield of sorghum to the amount of readily available phosphorus. The index of correlation of the data along this line has a value of $\rho = +0.812$. The standard error of estimate, $Sy = \pm 5.80$ grams, and its first zone is laid off above and below the line of relationship by the broken lines.

The correlation between the yield of sorghum when fertilized with nitrogen and potassium and the amount of readily available phosphorus obtained by the Truog method is less marked. The index of correlation of this relation has a value of $\rho = +0.652$; and the standard error of estimate is $Sy = \pm 7.67$ grams. The larger value of the index of correlation between the yield of sorghum and the amount of readily available phosphorus as determined by the modification of Truog's method as compared to that obtained by the unmodified method establishes the modification of the method as being the more accurate index of the crop-producing capacity of the soils with respect to phosphorus.

A similar improvement of the degree of correlation between the crop yield and the amount of available phosphorus as determined by the modification of the method over the degree of correlation between the crop yield and the phosphorus as determined by the unmodified method was observed in the yields of each of the three crops grown on these soils in the greenhouse. Since the value of the constant C in the non-linear relationship between the readily available phosphorus and yields of each of the crops on these soils was so small as to make the second degree parabola practically a straight line, the correlations between the amounts of readily available phosphorus obtained by Truog's method and the modification of the method and the yields of each of the three crops have been calculated along the linear relationship. All the values of these linear relationships are tabulated in Table 3.

TABLE 3.—*Summary of the correlations between plant growth on the pots fertilized with nitrogen and potassium and the amounts of "availalbe phosphorus" obtained by the Truog method and the modification of the Truog method.**

Crop	Method of determining the available phosphorus	Numerical values of the relation of plant growth to available phosphate			
		Intercept of the line, a	Slope of the line, b	Standard error of estimate, Sy	Coefficient of correlation, r
Peas.......	Truog	4.011	0.021	±3.05	+0.274
Peas.......	Modified Truog	3.464	0.017	±2.92	+0.384
1st sorghum	Truog	3.878	0.148	±7.93	+0.603
1st sorghum	Modified Truog	0.581	0.110	+5.81	+0.812
2nd sorghum	Truog	3.602	0.098	±6.70	+0.508
2nd sorghum	Modified Truog	1.199	0.075	±5.50	+0.706

*Correlation along the line $Y = a + bX$.

It will be noted in Table 3 that the relative values for readily available phosphorus obtained by the modification of Truog's method were much more closely correlated to the crop yields than were the values obtained by the unmodified method.

GREENVILLE SANDY LOAMS

By methods similar to those by which the Norfolk soils were studied, the responses to fertilizers in pot cultures in the greenhouse of 23 Greenville sandy loams have been determined. The readily available phosphorus of these soils has been determined by Truog's method and by the modification of the method. The values obtained, the total phosphoric acid content, and the yields of the first crop of sorghum grown on these soils are tabulated in Table 4. They are

TABLE 4.—*Total P_2O_5, available PO_4, and the yield of sorghum on pot cultures of 23 Greenville sandy loams.*

Soil No.	Total P_2O_5 in lbs. per acre	Available PO_4 in lbs. per acre		Yield of sorghum with N and K treatment, grams	Yield of sorghum with NPK treatment, grams	NK yield x 100 / NPK yield %
		Truog's method	Truog's method modified			
800	850	25	16	1.0	24.7	4.0
799	750	34	16	1.3	17.4	7.4
801	850	48	40	10.7	29.7	36.0
810	1,250	53	104	7.5	34.7	21.6
802	950	59	108	15.4	31.7	48.5
805	1,000	62	124	24.0	33.8	71.0
811	750	51	140	20.6	39.9	51.5
809	1,300	128	140	30.9	32.6	94.8
821	1,000	36	142	31.9	44.1	72.3
818	1,275	63	152	48.0	61.4	78.1
804	1,300	112	179	15.5	32.0	48.4
816	1,075	108	194	37.7	43.0	87.7
812	1,150	76	200	23.1	36.1	64.0
808	1,500	75	200	25.6	30.8	83.1
806	1,200	126	212	26.2	38.6	67.9
807	1,300	126	216	28.7	33.9	81.7
814	1,725	156	240	33.8	39.3	80.0
820	1,475	166	244	45.6	52.9	86.1
815	1,500	152	246	37.2	42.8	86.9
803	1,700	216	324	31.4	37.5	83.7
819	1,550	198	328	32.0	28.8	111.1
813	1,750	186	336	44.8	53.3	84.0
817	1,800	296	480	42.1	44.3	95.0
Mean	1,261	110.8	190.5	26.7	37.5	71.20

arranged in order of increasing amounts of readily available phosphorus as determined by the modification of Truog's method.

The readily available phosphorus by Truog's method ranges from 25 to 296 pounds of PO_4 per acre with an average of 110.8 pounds. By the modification of the method, the readily available phosphorus ranges from 16 to 480 pounds PO_4 per acre with an average of 190.5 pounds. Again, as in the case of the Norfolk soils, the average amount of available phosphorus obtained by the modification of the method is almost twice that of the unmodified method.

The yields without phosphorus fertilization on those soils which had a content of readily available phosphorus of less than 115 pounds of PO_4 per acre in no case exceeded 50% of their yield when fertilized with phosphorus. The yields without phosphorus fertilization on those soils which had a content of available phosphorus of more than 115 pounds of PO_4 per acre in every case exceeded 50% of their corresponding yields when fertilized with phosphorus.

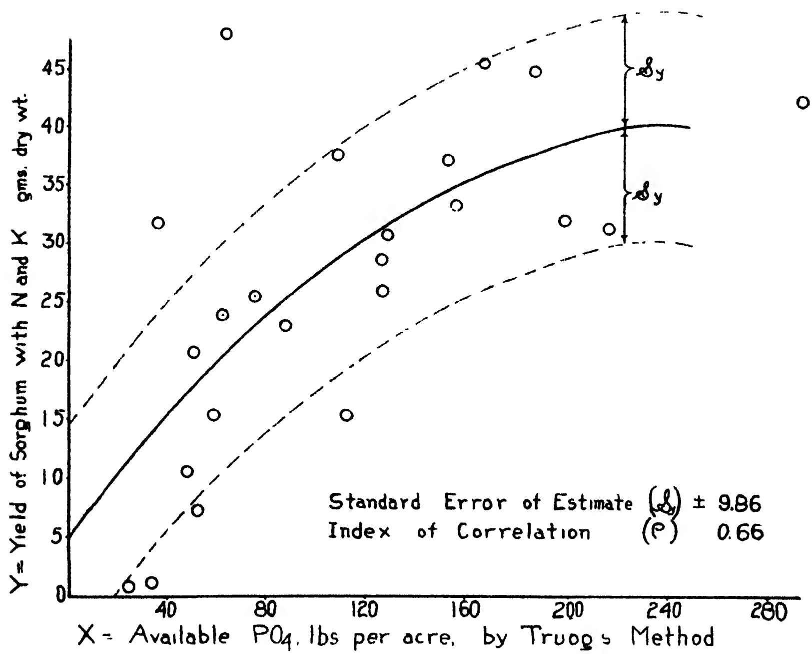

FIG. 3.—The relationship between the amount of readily available phosphorus as determined by Truog's method and the yield of sorghum on 23 Greenville sandy loams.

The yields of the sorghum and the amounts of readily available phosphorus as determined by Truog's method have been plotted in Fig. 3, and the second degree parabola curve has been fitted to the data by the method of least squares. Likewise, the data for the available phosphorus as determined by the modification of the method and the sorghum yields have been plotted in Fig. 4, and the second degree parabola curve has been fitted by the same method.

The correlation between the yield of sorghum and the amount of readily available phosphate as determined by Truog's unmodified method has an index of correlation value of $\rho = +0.661$. The stan-

dard error of estimate has a value of $Sy = \pm 9.86$ grams. The equation for the most probable relationship is $Yc = 4.926 + 0.284\ X - 0.000{,}590\ X^2$, in which X is the pounds of readily available PO_4

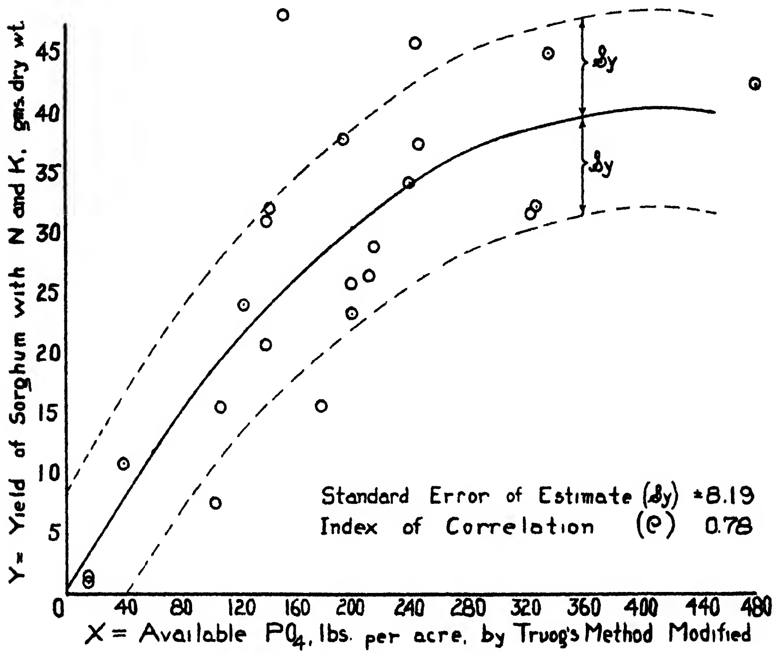

FIG. 4.—The relationship between the amount of readily available phosphorus as determined by Truog's method modified, and the yield of sorghum on 23 Greenville sandy loams.

per acre and Yc is the calculated or average yield of sorghum. By differentiating this equation, we have $\frac{dY}{dX} = 0.284 - 0.001{,}180\ X$.

Accordingly, $\frac{dY}{dX} = 0$, when $X = 241.073$, i.e., Y, the yield of sorghum, is at its maximum value when X, the readily available phosphate, is equal to 241.073 pounds of PO_4 per acre.

Likewise, the correlation between the yields of sorghum and the amounts of readily available phosphate as determined by the modification of Truog's method has an index of correlation value of $\rho = +0.785$. The standard error of estimate has a value of $Sy = \pm 8.20$, and the equation expressing the most probable relationship is $Yc = 0.519 - 0.199{,}384\ X - 0.000{,}252\ X^2$. The readily available phosphorus content of the soils at which the maximum yield of

sorghum was obtained is again calculated by differentiation. Thus, $\frac{dY}{dX} = 0.199,384 - 0.000,504\ X$, and $X = 395.60$ pounds of readily available PO_4 per acre when $\frac{dY}{dX} = 0$.

These values for the amounts of readily available phosphorus per acre at which maximum yields of sorghum are obtained are not considered as conclusive or final determinations of the average amounts of readily available phosphorus in soils that are necessary to produce a maximum yield of sorghum or crops. They have been calculated from these data to illustrate the possibilities of such correlations as these for predicting yields and making recommendations for phosphorus fertilization from data of this nature.

SUMMARY

The amounts of readily available phosphorus by Truog's method and by a slight modification of the method in a number of Alabama soils and the crop yields on these soils in the greenhouse in response to fertilizer treatments are reported.

Statistical correlations and graphical analysis of the relationship between the values obtained for readily available phosphorus and the yields of crops in the greenhouse are given.

Upon the information furnished by the interpretation of the data the following observations are made:

1. The relationship between the content of readily available phosphorus in soils and the yield of crops on these soils when given applications of all the needed fertilizing elements, except phosphorus, is most accurately expressed by a power curve, $Y = a + bX + cX^2 - - - -$, when the values used have a representative distribution.

2. When the relationship between field and greenhouse yields has been established and when sufficient data are considered the statistical correlation and graphical analysis of the relationship between the values for readily available phosphorus of soils and the greenhouse yield of crops on these soils can be used as a basis for (a) estimating the need for phosphate fertilization of other soils from their content of readily available phosphorus; (b) for predicting the relative yields of crops when grown without phosphate fertilization on other soils, from their content of readily available phosphorus; and (c) for predicting the approximate percentage in crop yields on soils in response to phosphate fertilization from their content of readily available phosphorus.

3. Any proposed laboratory method for determining the readily available phosphorus in soils can best be perfected by calculating the numerical values of the correlations between the crop yield and the amounts of readily available phosphorus as determined by the trial procedures of the method.

4. A comparative study of the various methods of determining the relative amount of readily available phosphorus in soils in which the correlations between the values for readily available phosphorus obtained by each of the methods and the yield of the crops are determined is the only way by which the correct evaluation of the various methods can be made.

AGGREGATE ANALYSIS AS AN AID IN THE STUDY OF SOIL STRUCTURE RELATIONSHIPS[1]

L. D. Baver and H. F. Rhoades[2]

From the physical point of view a soil may be pictured as being made up of mechanical and structural elements. The mechanical elements are the individual primary particles of various sizes, such as sand, silt, and clay. The structural elements are crumbs or granules of various dimensions which have been formed by the aggregation of the smaller mechanical elements. The extent to which a soil breaks up into crumbs or granules may be referred to as the "state of aggregation" of the soil. The different structural elements must be distinguished from the mechanical in order to obtain the complete picture of aggregation. Such a separation would be called "an aggregate analysis."

Various methods might be used for making an aggregate analysis. Any of the common sedimentation methods could probably be employed with certain modifications. Tiulin[3] uses a graded nest of sieves for separating the different sizes of aggregates. It is the purpose of this paper to discuss the value of the elutriation method for making these separations and for studying the stability of the aggregates.

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Paper presented before the Committee on Soil Structure at the annual meeting of the American Soil Survey Association, Chicago, Ill., November, 1931. Published with the approval of the Director. Received for publication March 7, 1932.

[2]Assistant Professor and Assistant in Soils, respectively.

[3]Tiulin, A. Th. Proc. Int. Soc. Soil Sci., 4: 49–54. 1929.

EXPERIMENTAL

The principle of the elutriator is based upon the separation of particles by a moving stream of water. Separation of the various-sized particles is accomplished by regulating the velocity so that it will just balance the rate of fall of the particle or aggregate as calculated by Stokes' law. Particles whose rates of fall are less than the velocity of the water will be carried with the water stream.

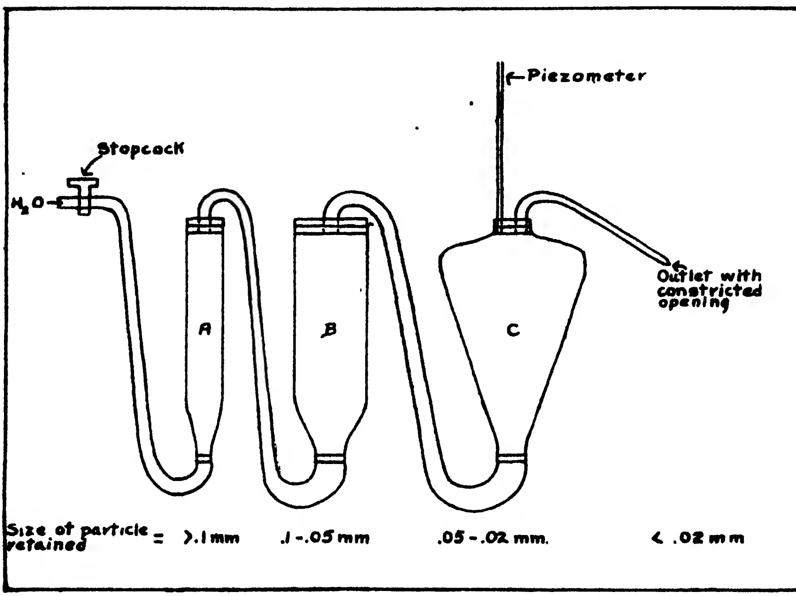

FIG. 1.—Diagramatic sketch of the Kopecky type of elutriator

The elutriator used in this study is a modification of the Kopecky type of apparatus as shown in Fig. 1. It consists of three elutriation tubes of different diameters. They are arranged with the tube of smallest diameter, A, connected directly to the water supply. This is the tube in which the soil is placed for analysis. The third elutriation vessel, C, is the largest in diameter and possesses an outlet and a piezometer tube. The piezometer is merely a small tube or capillary which indicates the velocity of water by the height at which the water ascends when it is flowing through the apparatus. The outlet tube is constricted somewhat so that a small back pressure is exerted. This causes the water to ascend in the piezometer. By adjusting the stopcock which connects the first elutriator tube with the water supply, any desired velocity of water can be obtained. The height of the water column in the piezometer is observed and recorded for

each velocity. After calibration of the apparatus, the desired velocity of water is always determined from the height of the water in the piezometer. A constant head of water is used as a source of the water supply. This is easily made possible through the use of two large carboys that are connected by a siphon and air tube.

The velocity of the water in the three tubes is so regulated that at the end of the analysis tube A will contain particles >0.10 mm in diameter, tube B particles from 0.10 to 0.05 mm, and tube C particles from 0.05 to 0.02 mm. Particles <0.02 mm in diameter will be carried over through the outlet tube into a large carboy. Elutriation is continued until no particles are carried over from one tube to another. This requires from 15 to 17 liters of water. About 1 hour is necessary to complete the separation and remove the contents of the tubes. The amount of material in each tube is weighed and the particles <0.02 mm in diameter are obtained by difference. Further separations of the fraction in tube A are accomplished by the graded nest of sieves generally used in ordinary mechanical analysis.

Several different soils were used in this study. Most of the discussion, however, will be confined to the results obtained with the surface horizons of the Grundy and Marion silt loams. The Grundy is a dark brown silt loam containing a relatively large amount of organic matter. The Marion is a light brown to gray silt loam and contains only a small amount of organic material.

Aggregate analyses were made of the moist samples as they were taken from the field. The moisture contents varied between 15 and 20%. The moist soil was used in order to simulate as nearly as possible the natural state of aggregation. When a soil is air-dried the whole system is dehydrated which results in the formation of more or less temporary aggregates. They rehydrate very slowly and do not usually represent the type of granules that are responsible for good structural relationships, especially in periods of excessive moisture.

The moist sample was gently sifted through a 2-mm sieve and then treated in various ways before being washed through the elutriator. A sample equivalent to 10 grams of dry soil was used. One sample of each soil was washed through the elutriator without any additional treatment. With this technic only the very unstable aggregates are broken up, those which are dispersed because of an excess of water. The small churning effect of the water as it passes through the elutriator does not affect the more stable aggregates. Other samples were shaken in a reciprocal shaker for periods of 10, 20, 60, 300, and 600 minutes. This procedure permits the determination of the relative stability of the aggregates as affected by the dispersing

action of water during the continued shaking. Finally, a sample was shaken with sodium oxalate as a peptizing agent in order to disperse the soil into its various mechanical elements.

The effect of the time of shaking on the percentage of different-sized particles in the Grundy silt loam as compared with the percentages when the soil is completely dispersed is shown in Fig. 2. As the time of shaking becomes longer there is a continuous decrease in the amount of particles > 0.05 mm with nearly a corresponding increase in the percentage of particles < 0.02 mm. The percentage of particles between 0.02 and 0.05 mm is practically unaffected by the shaking process. These relationships were found in all of the soils studied and indicate a high degree of aggregation in all fractions coarser than silt. The constancy of the number of particles from 0.02 to 0.05 mm in diameter may be explained by assuming either that aggregates > 0.05 mm break up directly into particles < 0.02 mm, or that there is a simultaneous breaking up of units of both sizes which is more or less compensating as far as the coarse silt fraction is concerned. Undoubtedly both processes take place at the same time. The data reported in this study were obtained with no shaking in order to show the maximum differences in the aggregation of the various soils. Ten minutes shaking before elutriation is recommended as a more satisfactory technic.

AGGREGATES CONTRIBUTING TOWARDS SOIL STRUCTURE RELATIONSHIPS

Tiulin has suggested that only aggregates > 0.25 mm are responsible for favorable structure relationships. In this investigation, however, no arbitrary limit is taken as representing the size of aggregates in which one is interested. The limits of the size of aggregates are taken from the size-frequency distribution curves of the soil, determined with and without dispersion. This is illustrated in Figs. 3, 4, and 5. (The diameter scale is reduced 1/10 between 0.1 and 1 mm in order to show more clearly the differences between the two curves. This explains the break in the curves). The diameter of the particles corresponding to the point of intersection of these two curves is taken as the lower limit of the size of aggregates which are responsible for the structural relationships in soils. This diameter would be expected to vary somewhat in different soils. Nevertheless, it is a definite limit which can readily be determined for every soil. It marks the point at which aggregates of a certain size and stability appear.

Since the state of aggregation is defined as the extent to which a soil breaks up into aggregates, it may be expressed as the total per-

centage of aggregates in a soil according to the following equation:

$$\text{State of aggregation} = \Sigma \left[\%\ \text{aggregates} \right]_a^b \quad (1)$$

where

a = lower limit of size as determined from the distribution curves of the size of particles in the soil, with and without dispersion.

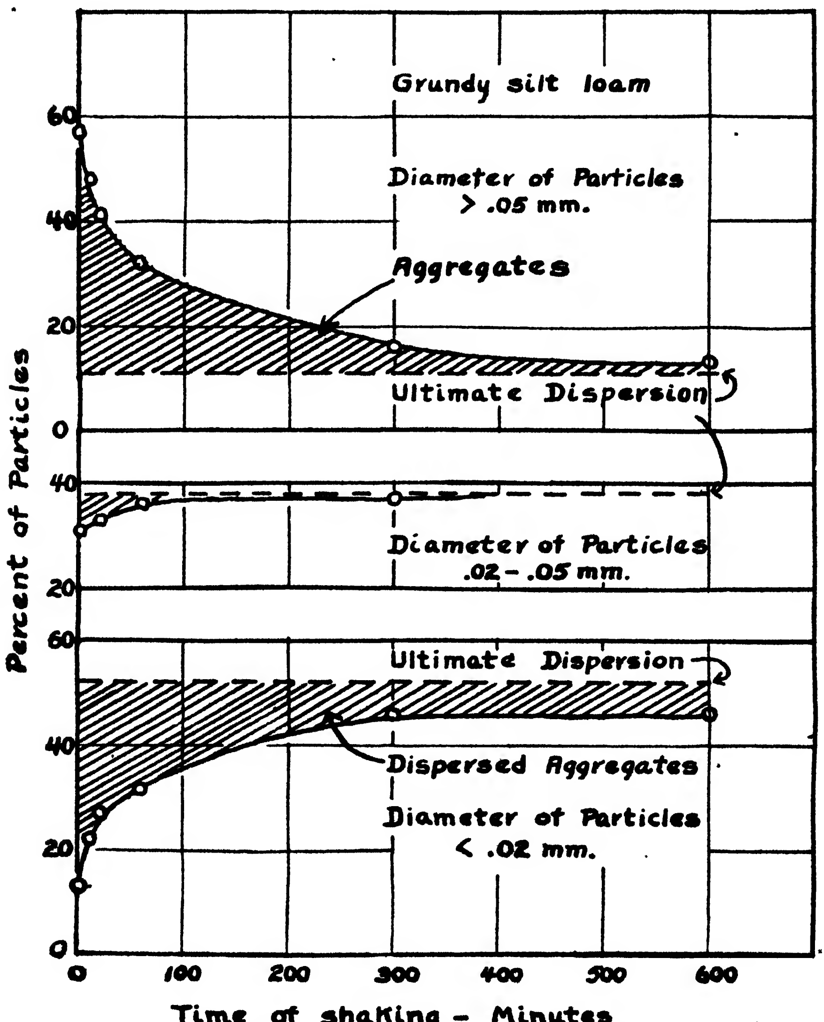

FIG. 2.—The effect of the time of shaking upon the size of particles in the soil.

b = upper limit of size as determined by the stability of the aggregate in an excess of water.

This method of calculation has been used in Figs. 3, 4, and 5 in which the state of aggregation of three different soils is shown by the shaded area between the two distribution curves. The data from

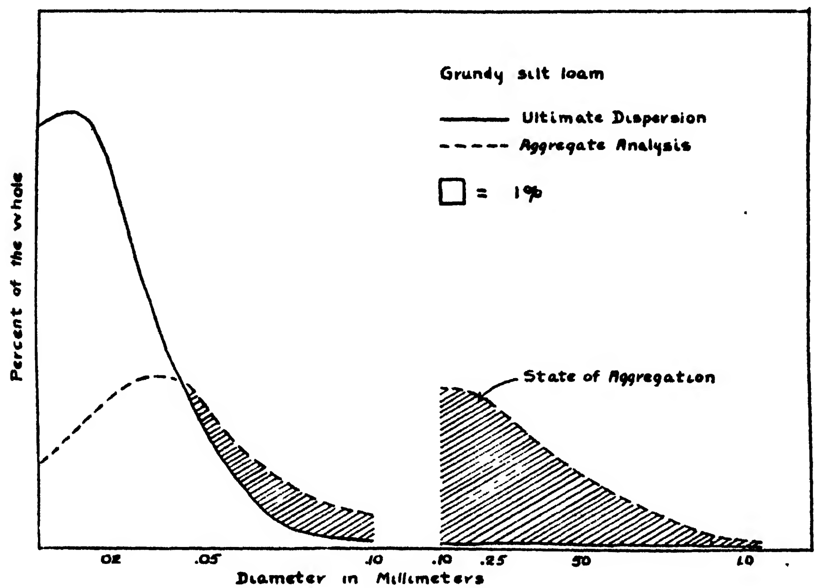

FIG. 3.—Size-frequency distribution curve of the Grundy silt loam with and without dispersion. (Diameter scale reduced 1/10 between 0.1 and 1 mm.)

which these curves were made are given in Table 1. It is evident from an analysis of the results that the lower limit of the size of the soil aggregates as determined from the distribution curves is about 0.05 mm. In other words, any aggregation within the silt fraction cannot readily be determined without subjecting this fraction to some dispersion process. Such a procedure might be valuable for technical purposes; however, preliminary correlations between the state of aggregation and other physical properties of the soil do not warrant as yet a more detailed study within these limits.

A comparison of the state of aggregation of the various soils shows some very interesting facts. Their mechanical compositions do not vary greatly. On the other hand, there are marked differences in the percentage of aggregates present. Considering only the surface soils, the percentage of mechanical units $>$ 0.05 mm ranges from 8.6 in the Marshall silt loam to 13.3 in the Marion. The percentage

of aggregates varies from 19.2 in the Marion to 46 in the Grundy silt loam. In other words, about one-half of the total particles in

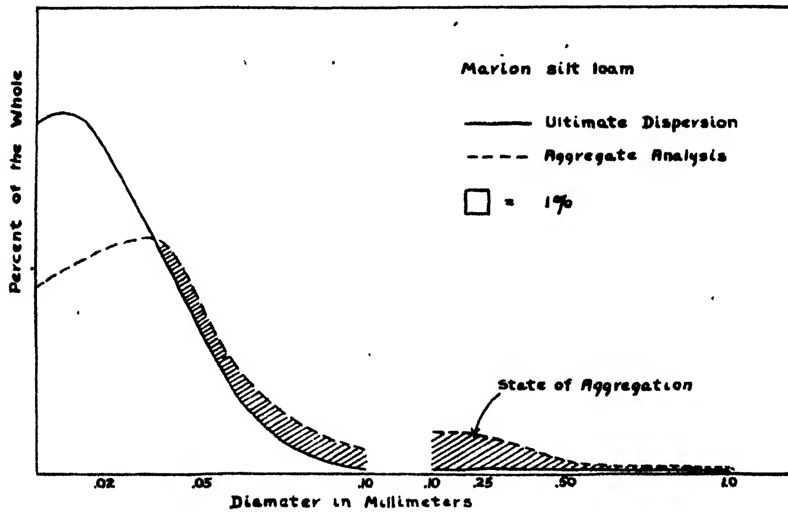

FIG. 4.—Size-frequency distribution curve of the Marion silt loam with and without dispersion. (Diameter scale reduced 1/10 between 0.1 and 1 mm.)

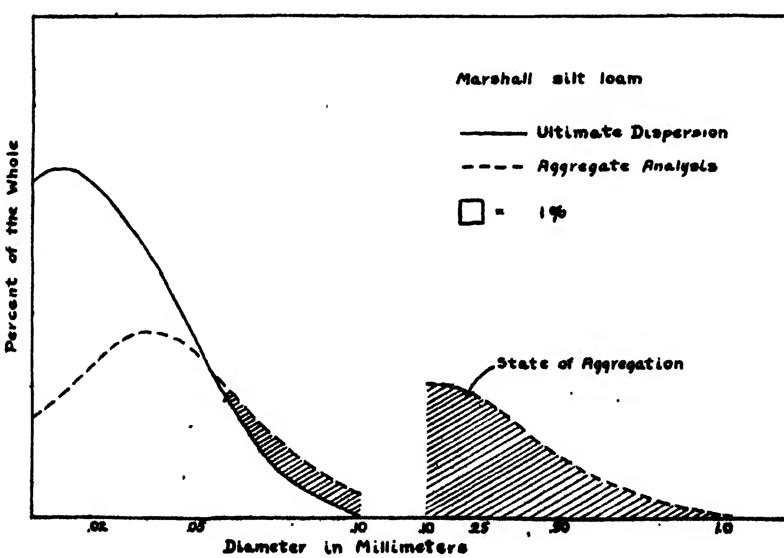

FIG. 5.—Size-frequency distribution curve of the Marshall silt loam with and without dispersion. (Diameter scale reduced 1/10 between 0.1 and 1 mm.)

the Grundy are in a state of aggregation, whereby only about one-fifth are in such a state in the Marion. The former is distinctly granular; the latter possesses almost a single-grained structure. These differences in the state of aggregation are reflected in the various physical properties of the soils as will be discussed in a later publication.

An aggregate analysis of the Marion silt loam profile shows that there is very little granulation in any of the horizons. This soil has been thoroughly leached; consequently, most of the factors which are responsible for stable aggregate formation have been removed.

Not only is it important to know the percentage of aggregates in a given soil, but it is also worth while to know the degree to which

TABLE 1.—*Aggregate analyses of different soils.*

	Marion silt loam, A_1		Marion silt loam, A_2		Marion silt loam C_1	
Size of particles, mm	Aggregate analysis %	Ultimate dispersion, %	Aggregate analysis %	Ultimate dispersion, %	Aggregate analysis %	Ultimate dispersion, %
>1	1.40	0.85	1.80	0.85	1.35	0.65
1–5	2.85	1.30	2.80	1.90	4.95	1.85
0.5–0.25	3.40	0.80	1.65	1.00	4.40	1.90
0.25–0.10	4.10	0.50	1.00	0.50	4.40	2.25
0.10–0.05	20.80	9.85	12.95	7.50	15.20	12.15
0.05–0.02	42.65	43.80	45.40	47.35	36.10	40.70
<0.02	24.70	42.90	34.40	40.90	33.60	40.50
>0.05	32.55	13.30	20.20	11.75	30.30	18.80
State of aggregation, %	19.25		8.45		11.50	
Degree of aggregation, %	59.1		41.8		37.9	
	Grundy silt loam, A_1		Marshall silt loam, A_1		Summit silt loam, A_1	
Size of particle, mm	Aggregate analysis %	Ultimate dispersion, %	Aggregate analysis %	Ultimate dispersion, %	Aggregate analysis %	Ultimate dispersion, %
>1	2.30	0.40	0.75	0.10	0.45	0.25
1–5	9.80	0.85	6.80	0.10	1.90	0.65
0.5–0.25	15.45	0.75	13.55	0.10	7.90	0.70
0.25–0.1	14.45	0.45	11.85	0.15	14.20	0.55
0.1–0.05	14.50	8.05	20.75	8.15	21.05	7.00
0.05–0.02	30.65	37.80	32.50	49.60	38.90	44.50
<0.02	12.90	51.70	13.80	41.80	15.60	46.35
>0.05	56.50	10.50	53.70	8.60	45.50	9.15
State of aggregation, %	46		45.1		36.3	
Degree of aggregation, %	81.4		84		79.8	

the soil fractions between the limits a and b in equation 1 are aggregated. For example, the state of aggregation of the Marshall silt loam was found to be 45.1%; that is, the soil contains this percentage of aggregates $>$0.05 mm in diameter. The total percentage of units $>$0.05 mm, including structural and mechanical elements, is 53.7 The degree of aggregation of the Marshall, therefore, is 84%. That is to say, 84% of the total fractions $>$0.05 mm are stable aggregates. Some soils might show a high percentage of total fractions (aggregates and primary particles) larger than a certain size but have a low degree of aggregation. Such would be the case with soils containing a fairly large amount of sand. On the other hand, it is possible for all of the units above this size to be aggregates in which case these particular soil fractions would be 100% aggregated.

It is interesting to compare the aggregation of the Summit and Grundy silt loams. The state of aggregation of the former is 36.3%, that of the Grundy 46%. The degree of aggregation, however, is nearly the same in both soils. This means that the percentage granulation of the soil fractions larger than 0.05 mm is similar.

This concept of the degree of aggregation of soil fractions of a certain size (the size determined between the limits as previously discussed) is especially useful in studying the stability of the structural aggregates. The relative stability of the aggregates is easily determined by measuring the degree of aggregation of the soil as affected by the time of shaking in water. Aggregates that remain stable during the shaking process should be fairly resistant to dispersion under excessive moisture conditions in the field.

A comparison of the stability of the aggregates in the Grundy and Marion silt loams is shown in Fig. 6. The lower limit of the soil fractions considered as aggregates is 0.05 mm, as previously determined from the distribution curves. Of the total percentage of fractions $>$ 0.05 mm, 81% are aggregates in the Grundy and only 59% are granules in the Marion. At the end of 10 minutes of shaking, these percentages have decreased to 79 and 41, respectively. One hour's shaking caused a decrease in the state of aggregation of the Grundy to 74%. This was lowered to 20% in the Marion. These data clearly show that the Grundy silt loam possesses not only a higher degree of aggregation but also much more stable granules than the Marion. The differences are of utmost importance in the structural relationships of these soils.

The data in this investigation show that elutriation is well-adapted to measurements of the aggregation of soils. A determination of the state and degree of aggregation of various soils promises to give a

fairly accurate picture of their structural relationships. Further studies are in progress to correlate the aggregation of soils with other physical properties.

Several difficulties are met in making aggregate analyses of soils. In the first place, the soil must be in the natural moist condition to obtain the best results. Dehydration tends toward the formation

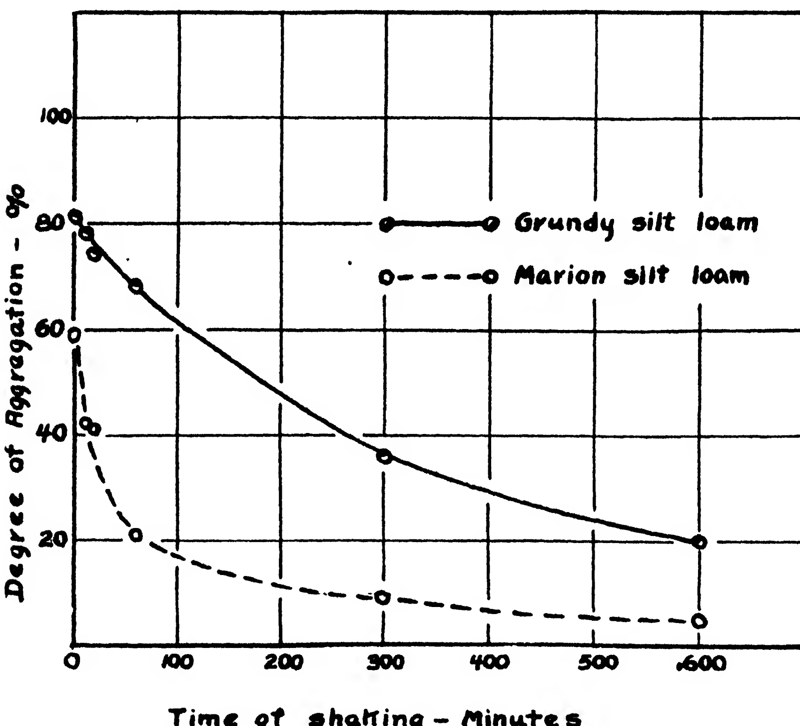

FIG. 6.—The stability of aggregation in two different soils.

of temporary aggregates as has been previously discussed. In the second place, there is a possibility in some instances that the flocculating electrolyte may be removed by elutriation which would result in a dispersion of the natural aggregates. These difficulties are being investigated.

In the third place, it is extremely hard to obtain the true picture of the granulation of heavy clay soils. The high plasticity of these soils in the moist condition practically prevents their being dispersed into smaller units. If the soil is air-dried and then moistened, a large number of aggregates is formed. They do not represent the correct state of aggregation since they are not stable over a period of time in

an excess of water. As a result, a heavy, puddled clay is liable to show a high state of aggregation after drying even though in the field it has almost a single-grained structure. These difficulties may be overcome in some cases by allowing the moist clod to stand in water for several weeks before determining its aggregation. Dehydration in alcohol has also been found to disperse the clod into its finer fractions. Caution must be used in these cases, however, in order to obtain the true picture of the granular nature of the soil.

SUMMARY

The elutriation method for measuring the aggregation of soils is described and discussed.

It is suggested that the state of aggregation designate the extent to which a soil breaks up into aggregates and that the stability of structure refer to the stability of the structural aggregates.

An equation is suggested for characterizing the state of aggregation of a soil.

The percentage aggregation of the total soil fractions between the limits a and b of the equation is designated as the "degree of aggregation" of the soil.

The stability of structure is measured by the change in the degree of aggregation as affected by the time of shaking of the soil in an excess of water.

A comparison is made of the aggregation of several different soils.

A PROPOSED DESCRIPTIVE SYMBOLISM FOR SOIL HORIZONS[1]

D. W. PITTMAN[2]

The article by Sokolovsky[3] on nomenclature for horizons in soils has suggested the publication of a similar system possibly even more descriptive which has been used by the author for brief personal notes and classroom work.

From observations made at the Second International Congress of Soil Science in Russia in 1930, it seems that Dr. Sokolovsky is correct in his conclusion that there is no longer universal agreement as to the meaning or application of the symbols A, B, C, and D as applied to soil horizons. The original designation of A = surface or true soil; B = transitional soil; and C = subsoil, has been discarded, since it is now recognized that more than three horizons may be true soil in the sense that they owe their character to their ,present environment. The later distinction, as used by Glinka[4] and by the American Soil Survey Association[5] of A = eluvial; B = illuvial; and C = subsoil, is also open to criticism, especially when applied to the soils of the arid and semi-arid region where the surface horizons are often zones of accumulation. Also, as suggested by Sokolovsky and by Nikiforoff[6], a horizon may be eluvial with respect to one material and illuvial with respect to another. Besides, this distinction is based on an assumed origin of the horizon which might prove to be incorrect. It would seem better for the designation of the horizon to be based on observable properties of the horizon itself rather than on deductions therefrom.

Dr. Sokolovsky proposes the following designations:

H = humus horizon—formerly A_1
E = eluvial horizon—formerly A_2 of podzol

[1]Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director April 9, 1932. Received for publication April 14, 1932.

[2]Associate Agronomist.

[3]SOKOLOVSKY, A. A rational nomenclature of genetical horizons in soils. Contr. Ukrainian Inst. for Soil Res., 3. 1931. (In English.)

[4]GLINKA, K. D. The Great Soil Groups of the World and Their Development. Trans. from the German by C. F. Marbut (1927). Ann Arbor, Mich.: Edwards Brothers. 1927.

[5]SHAW, C. F. Soil terminology: A glossary or list of technical terms used in soil descriptions and in soil classification. Amer. Soil Survey Assoc. Bul. 9: 36–37. 1928.

[6]NIKIFOROFF, C. C. History of A, B, C. Amer. Soil Survey Assoc. Bul. 12: 67–70. 1931.

I = illuvial horizon—formerly B
P = parent rock material—(petra)
Gl = "gley" horizon—formerly G
K = horizon of carbonate accumulation
G = horizon of gypsum accumulation
S = horizon of accumulation of soluble salts
T = horizon of turf or raw humus—formerly A_0

By using two or more letters when necessary and adding a subscript number indicating the thickness of the horizon in centimeters, this designation becomes quite descriptive. Thus, the surface mineral soil of a certain podzol becomes not "A_1" but "HE_{14}".

This system seems to be an improvement over the old but is still lacking in that it fails to take into account horizons whose distinguishing characteristics are largely structural, such as the prismatic or columnar horizons of many chernozems or alkali soils or the platy horizons of many alkali soils.

In the system suggested below it is proposed to retain the capital letters and subscripts as now used (where the usage is fairly standard) to designate the position of the horizons, but to add a group of small letters to serve as a brief description of the horizon. The vowels are reserved to indicate structural differences, while the other letters are used rather arbitrarily to distinguish differences in color and accumulations or residues which can be readily detected in the horizon. Some letters are intentionally omitted as they are difficult to transliterate into the Russian.

The designation of the letters is as follows:

b = dark coloration due to organic matter—usual in surface horizons
d = red coloration—as of hematite
f = brown coloration—as of iron and organic matter
g = buff or yellow coloration—as of limonite
j = bluish coloration—as of iron protoxides
k = white or light grey coloration as of silica in podzols or the light grey of arid calcareous soils
l = mottled coloration
m = organic accumulation—peat or muck materials—the A_0 horizon
n = sodium or soluble salt accumulation—determined by appearance or simple tests
p = silica accumulation—as in A_2 of podzols
r = sesquioxide accumulation—clay
s = lime accumulation as shown by effervescence
t = gypsum accumulation as shown by appearance or simple tests
v = horizon of concretions or "ortsteine"
z = parent material—unaltered by present environment

a = columnar or prismatic structure—units developed vertically
e = cubiform structure—units approximately same size in all dimensions
i = plate-like structure—units developed horizontally
o = loose, single grain, or structureless condition as of sand or A_2 of podzols
u = puddled structureless condition
y = compact, impervious hardpan

It is also possible to indicate those characters which are well expressed by bold-faced type or by underlining, while those more feebly expressed are in ordinary type.

By this system the typical podzol examined by the Second International Congress of Soil Scientists at Pavlovsk Park would be described as follows:

A_0—m (8–10 cm)
A_1—**b o** (7–10 cm)
A_2—**k p o** (15–20 cm)
B_1—**g r** y (20 cm)
BG_1—**j r** y (10 cm)
B_2—**g l** o (40 cm)
BG_2—**z g o** (sandy)

A chernozem (slightly degraded) examined at Kharkov would be described as follows:

A —**b e** (36 cm) (trace k)
B_1—**b** a y (27 cm)
B_2—b r a y (23 cm)
C_1—g **s** (69 cm)
C_2—g **t** s (100 cm)
D —z s (loess)

The deep columnar alkali (solonetz on chestnut) observed near Gashun would be described as follows:

A —**k i** (8 cm)
B_1—**f a** (13 cm)
B_2—**f** a **y** (10 cm)
B_3—g s a **y** (10 cm)
C_1—g s **t** a (37 cm)
C_2—g s t (62 + cm)

A local alkali soil near Logan, Utah, would be described as follows:

A_1—b n s e (20 cm)
A_2—f **n** s **e** (10 cm)
B —k **n s a y** (34 cm)
C —z l (gj) s o (sandy)

While this system may possibly be too complex for general acceptance in standard technical literature, the above examples show that it is relatively easy by slight additions to make the present nomenclature of soil horizons quite definite and descriptive.

AGRONOMIC AFFAIRS

NEWS ITEMS

Microbiology is the title of a new journal being published in Russia under the editorship of Prof. W. S. Butkewitch. It is devoted to general, agricultural, and industrial microbiology and is to be published four times a year, three numbers having appeared thus far in 1932. The price is 8 rubels a year. Papers appearing in the early numbers deal with physiology, biochemistry, and morphology of micro-organisms; relation of micro-organisms to chemical industries and to foodstuffs; the rôle of micro-organisms in the treatment of flax, skins, wool, and other agricultural products; the rôle of micro-organisms in milk and milk products and in water purification; soil microbiology; and microbiology in its relation to plant and animal diseases. Each paper is followed by a detailed summary in a foreign language.

Two new types of direct-reading potentiometers are now being offered by Hellige, Inc., of New York City, which are said to combine the accuracy of the electrometric method with the advantages of this method under circumstances which prevent a colorimetric determination. Both types are constructed to ensure simplicity of operation without sacrifice of accuracy, and are credited with giving accurate results even when operated by those with limited experience or by unskilled workers. A circular describing the apparatus and giving full details of its operation may be obtained from the manufacturer.

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THE MYSTERY OF THE SOIL[1]

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"Nature in the raw" may be seldom "mild," but mild or harsh, it has always been a deep-dark mystery to the limited intellect of mankind. The ancients reverenced everything which was mysterious to them, believing that "the gods" were responsible. They feared to attempt an examination of any of the things which mystified them lest "the gods" be angry and visit their wrath upon the rash, presumptuous investigator. Hence it was that the multitude of natural phenomena which forced themselves upon the attention of those primitive people were awe-inspiring and interesting, but not at all understood and, indeed, not even the subject of investigation! Nature was accepted as it was—the gift of the gods and under the control of the gods! The only thing necessary was to keep the gods properly propitiated and everything would be lovely!

This calm, comfortable philosophy of the "early settlers" was gradually replaced by the "inquiring mind" of the beginnings of so-called civilization. The gods were often difficult to conciliate and in spite of all manner of sacrifices, things did not always go right. Certain individuals became so curious that they braved the wrath of the gods and delved into the various mysteries. And lo!—nothing happened to them! The wrath of the gods became a thing to be mocked and ignored! And so investigational work began! Soon the physical sciences appeared and gave their aid toward the solution of nature's mysteries. Civilization developed, science developed, research developed! Or as some would have it, research began, science appeared and as a result civilization progressed! Perhaps so! At any rate many of the former mysterious occurrences were soon "exposed"

[1]Presidential address delivered before the twenty-fifth annual meeting of the Society held in Washington, D. C., November 17, 1932.

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as natural happenings. The old myths were largely exploded. The "why" of numerous strange things in nature has now been discovered. Science and knowledge and civilization have increased and developed at an amazing rate and the accumulation of known facts regarding nature has become stupendous.

But have the mysteries of Nature all been solved? Far from it! We become so enamoured of our remarkable achievements that we are inclined to feel that we have just about reached the peak of scientific development, the summit of knowledge. Those who follow us, will have trouble in finding problems to work on—mysteries to solve! In the most reprehensible but withal expressive language of the day "Oh, yeah—you're telling me?"

Do not be deluded, complacent, sated with the extent and importance of the achievements which have been made in all the natural science lines. Mr. Sherlock Holmes and his able assistant, Dr. Watson, as investigators of the mysteries of Nature will find plenty of mysterious occurrences in the everyday world around us, upon which to test their intuitive powers, their scientific deductions, their amazing analytical methods! The unsolved mysteries of Nature are still legion! There is very far from any dearth of problems, upon which the students of the future may test their "detective" powers.

Among all the mysteries in the world of Nature, the mystery of the soil stands out prominently at the present time This is largely due to the fact that Soil Science, among all the sciences of nature, has been late in developing. It is only comparatively recently that it has really reached an individual science basis. Just why it should have been so slow in developing is difficult to determine. But it is probably due to the fact that the study of plants and animals proved so extremely interesting and important and there was nothing attractive in working with "dirt." One of the most deplorable and maligning beliefs of many people, including some scientific workers, has been that soil was "dirt." It has taken years and will take many more before we shall hear the last of that great fallacy! One of the first lessons we have been teaching for many years in our Soils courses at the Iowa State College is the distinction between soil and dirt and woe betide the student who refers to soil as dirt—at least in our presence! We really get them broken of the habit. And I am inclined to believe that we are making some progress with all agricultural people. Not nearly so many persons come into our office and say "I have some dirt to be tested."

Logically the study of soil should have been carried on much more intensively and extensively years earlier. The soil is the basis of all

agriculture. It is fundamental to food production—to the feeding of the human race! But too long it was looked upon as a mere inert, static medium, upon which plants grew or did not grow—a material which covered the surface of the earth and differed somewhat in various places, because of variations in the rocks from which it was presumably formed, because of the climatic conditions to which it had been subjected, and because of the character of the vegetation upon it. Here I may digress a moment to call your attention to the fact that this is one of the mysteries of the soil which is still unsolved. Perhaps it never will be! The question is like the old one "which came first, the chicken or the egg?" Are the characteristics of soil types determined by the type of vegetation occurring on them in a native or virgin condition? Or is the type of vegetation a result of the soil type character—at least in part? Some of you may have an answer to the question. Personally, I have. But whatever view is held, there is bound to be discussion. I submit that it is one of the most intriguing mysteries of Soil Science, which may engage our spare moments when we have nothing more vital to occupy us. There are so many other more important mysteries demanding solution!

But whatever the views of the early agricultural scientists, whatever the reasons, the fact remains that it has only been comparatively recently that the soil has received the attention of scientists, which it should have had long ago. It was not until the emphasis was placed upon the soil *as soil*, not as a geological, chemical, or physical material, not merely as a material which would support plant growth, but as a dynamic material *of itself* and *in itself*, a place of the deepest, darkest mysteries of nature, that a real study of the soil began.

Now there has developed a real Soil Science—a science established by the accumulation of a vast mass of facts, the solution of many of the simpler mysteries, occurring beneath the surface of the earth, beyond the vision of man, the evaluation and interpretation of data and observations made incidentally and often accidentally over long years of what may be called the period of "soil ignorance", and by the systematic, scientific study of soils *as soils*.

I would not for a moment minimize the value of the work of those early agricultural chemists and of the pioneer soil workers who sought so diligently to uncover some of the laws governing the growth of plants upon soils. Their labors were not in vain! They paved the way for the development of the real Soil Science. Many of their results are of unquestioned significance when interpreted in the light of our present knowledge and from a Soils viewpoint.

One of the most interesting observations to be made at the present

time, as Soil Science develops and as Crop Science develops, is that these two sciences are not growing apart but they are coming to depend more and more upon each other. Each is finding the other science of more and more use to it. The two together make up what we call Agronomic Science and both are vital to Agricultural Science. They should develop side by side, hand in hand. Only by the most intimate contact and the fullest recognition of the accomplishments of the other science, will either make the most progress and contribute all that it should to the agriculture of today and tomorrow. May I point out that here in the American Society of Agronomy, these two young sciences are meeting together in annual meetings, in the columns of our Journal, and in the exchange of ideas among the workers in both lines. It's a worth while, a very desirable—yes, I believe an essential union of these two sciences! Let us go on into the future—as we have for the past twenty-five years—hand in hand, realizing that there are real benefits to be derived by both crops and soils specialists by this intimate contact, and that each science must draw upon the other for all the clues available to help in solving its mysteries.

Now I have labelled this address "The Mystery of the Soil," but there are really numberless mysteries still to be solved. All may be grouped together, however, in one great mystery, toward the solution of which, the solving of each minor mystery will contribute. While I would not venture to discuss the mysteries of Crop Science, I submit that all the various soil mysteries affect crop problems. Then, too, practically all the soil problems have a crops angle or need the aid of some crops studies to provide a full and complete solution.

The mystery of the soil is an extremely complicated one with many ramifications. In other words, there are so many characters in the mystery play, the scenes are so varied, the scenery and stage settings are so confusing that there are too many clues. There are so many who might have committed the murder and had good reason for doing it, there are so many finger marks and foot prints, so many involved situations, so much moving of the furniture, so many spots upon the rugs and wall paper, such a vast accumulation of peculiar happenings before the murder and immediately following it! None of the suspects can establish an alibi. No one can answer all the hypothetical questions put by the expert detectives. The trained blood hounds lose the scent. The heavy rains obliterate traces left by the suspects. Some of the important witnesses disappear under most mysterious circumstances. At midnight, with deep black, dank darkness all around, an apparition with ghostly face and long

trailing robes appears and some one dies of fright. A detective goes crazy and must be calmed and restored to sanity. Thunder storms of terrific intensity occur frequently with torrential rain and blinding lightning flashes! Poison appears in the food, the water supply is contaminated or fails utterly. Then just as it appears that the mystery will be solved and the murderer apprehended, the plot thickens and then thickens some more and one who at first seemed to be a deep-dyed villain turns out to be a blue-eyed lover whose idiosyncrasies which have so confused the sleuths and perturbed all the characters are found to be due to the "insanity of love." Then the female vamp appears in her usual rôle and one wonders why she was not murdered instead of the good, kindly, beloved, gracious but withal rich old gentleman whose dead body was found in the grove of the fine old country estate not far from the mansion itself which was filled with guests, relatives, and servants, as motley a crew as could possibly be conceived. Several villains appear on the scene and numerous heroes and heroines. Invisible forces, the so-called occult, get into action. The whole mystery is soon resolved into an extensive series of sub-mysteries, all of which must be solved before the "killer of the good old man" can be revealed. "The Phantom of Crestwood" or "Who Killed Jenny" is a simple, very simple mystery compared to that which I have outlined. Those of you who have been so frivolous as to read mystery stories may recognize some of the references. Most of you probably have spent or misspent some time in such vain pursuit of entertainment. But they do make wonderful vacation reading material, real relaxation!

Now I shall not attempt to go back over this extravagant outline of a murder mystery as it might have been conceived by a combination of Sherlock Holmes, Charlie Chan, and all the other famous detectives who have evidenced the super-intellect which would solve all mysteries, to point out all the analogies to the mystery of the soil. Striking comparisons are possible! I am sure you will all recognize them.

The good kindly old man who was killed, thus furnishing the theme of the mystery, might be looked upon as old "Father Agriculture." At the present time it looks as if that murder had really been committed, and the fixing of the responsibility an impossibility! But our victim in the Soils mystery, is the poor, old, worn-out soil, the once healthy, vigorous, kindly support of the whole family. Killed in cold blood, without mercy or the slightest consideration of the consequence—under the most unusual conditions, a whole bevy of witnesses, villains and heroes, friends, relatives and enemies, and mere

on-lookers. In fact; with the whole world looking on. And the scene laid under the most complex situation imaginable. Can anything more complex be imagined than the soil? Physical forces, chemical forces, biological forces, yes, even what seem to be occult forces are operating. Who or what killed the old man? Was it some physical force, some chemical force, some biological force or was it an economist, who frightened him to death? The investigation of the mystery has begun. Soil Science has undertaken the task in a vigorous, logical way. But there are so many subsidiary mysteries to be solved first that progress is necessarily slow. Eventually the whole horrible plot will be exposed in all its appalling details. At present we are in the midst of the mystery story. We are making progress, although at times the plot thickens and we become much confused. Clues appear at every turn, some false and useless, some adding to the facts which will finally give us the solution of the mystery.

There is not time to enumerate all the subsidiary, secondary mysteries which are now engaging our attention. But some of the more important may be listed. Others will occur to all of you. In fact, it is difficult, if not impossible, to think of even one of the soil questions which we are being called upon to answer now without realizing that some mystery is involved. You will say "why we do have definite fixed answers to many soil questions—we have established some facts." True, but I challenge you to cite a single one which cannot be shown to be surrounded by some mysterious circumstances *under certain soil conditions*. We may know what happens to a crop grown on a soil treated in a certain way, or on many soils receiving a definite treatment. But do we know why? No—it's a mystery! Do we know that the same effects are occurring in all soils? No—it's a mystery!

Now for some examples which will indicate specifically what I have been discussing in more or less general terms. First, let us consider liming. We know that liming benefits the growth of legumes on most acid soils. But some legumes grow well on certain acid soils and not on others. Why? Buffering in the soil? Perhaps. If so, what is buffering? Adaptation of the crop or variety? (A crop science problem). If so, why and also how? Inaccurate tests for acidity or apparently good tests which do not work under the particular conditions?

Inoculation of legumes occurs best on non-acid soils. The legume bacteria seem to prefer basic conditions for their growth. In fact, frequently they will not grow under acid conditions. But sometimes they do! Sometimes well-inoculated legumes are found growing in

strongly acid soils. Why and how? Is it an adaptation of species? Then, too, if the legumes are inoculated, are they drawing upon the free nitrogen of the atmosphere? If so, how much and how? Do nodules on the roots of legumes mean fixation of nitrogen? Not necessarily. It's a mystery! When and how do legume bacteria fix nitrogen? Why will they utilize atmospheric nitrogen when in the nodules but refuse to do it when growing alone under presumably very favorable conditions? If there is an abundant supply of nitrogen in the soil, will nodules form? If not, why not? If they do form under such conditions, are they of any value or mere adornments, useless appendages, or parasitic infestations? It's all a mystery!

When we consider the whole legume problem, there we find many of the most interesting and important mysteries. There's the Dr. Jekyll and Mr. Hyde existence of the Rhizobia. Sometimes of one form, size, and shape, sometimes of another; sometimes present, sometimes absent; sometimes active and efficient, often weak and ineffective. Variations in strains occur but they are not constant. Certain characters vary with the strain. When are they weak organisms and when strong? How can they be distinguished? Why do they vary? Then there is the problem of cross-inoculation. Why do some bacteria inoculate several legumes while others infect only one variety? But enough of this particular mystery! Some progress has been made in the solution of this mystery of legume inoculation and the bacteria involved, but it is still far from being fully solved!

To return to liming and acid soils, it might seem that there we have a mystery that has been solved. But far from it. What kind of lime shall be used? How and how often? What does it do to the soil? Can we put on too much? How about magnesian versus calcium limes for soil use? And there are a multitude of other questions involved in liming, the answers to which are not yet available. What is soil acidity? Are soil acids toxic to plants? Is there a soluble aluminum toxicity? Who can say—*for all soils?* Liming of soils presents a mystery which has been studied for a long time, but it is still unsolved. Let anyone who thinks it is, stand forth and answer some of the above questions!

Again, may I emphasize the fact that Crop Science is involved in both the soil mysteries just discussed, liming and legume inoculation. And there can be no question of the significance of both these problems to the agriculture of extensive areas throughout the land. Fortunately, practical agriculture is not obliged to wait for the final solution of the soil mysteries before profiting by the facts uncovered

in the course of the study of the mystery. The valuable effects of growing inoculated legumes and of liming acid soils have been generally recognized and these practices have become basic parts of all sound soil management programs. But the final solution of the mystery will place these farming operations upon a more sure, sounder basis.

Then we may consider the still more complex problem of organic matter in soils. The mystery of this material, its decomposition and its functions in soils is still only in the initial stages of solution. It varies so widely in composition, character, and rate of decomposition and the variety of products is so great that it presents a whole series of mysteries all its own. Much has been learned about organic matter and quite recently contributions of fundamental significance have been made. But the story is far from told! What is the reason for the difference in the rate of decomposition of certain green manure crops? Why do non-leguminous green manures prove as effective as legumes under certain conditions? Why and how and when should green manuring be practiced at all? What is the effect on various soils? Why do cornstalks decompose in the soil and how? What fertility value have they? A very important question now, by the way, in connection with the industrial utilization of agricultural waste. How about grain straw? How should it be utilized? Has it any fertility value? When and why does it have a deleterious effect on soils and crops? How is it decomposed in the soil? What are the effects of different straws? What is the influence of certain fertilizers such as nitrates on the effects of straw plowed under in soils?

How about artificial manures? Can they be made practically, from waste materials, from straw, etc.? What are their effects on soils? How many other forms of organic matter find their way into the soil—what do they do? How are they decomposed? What effects do they have on crop growth?

Then there is farm manure. How much is really known about farm manure and its effects on soils? Imagine a material as complex as soil, treated with another material such as farm manure, just as complex if not more so, and then attempt to figure out what happens. Is it any wonder that it constitutes a mystery? But it is an interesting and an important mystery. Is it the plant food in the manure which makes it of value? Is it the chemical effects, or is it the biological effects? Studies have been made along this line but owing to experimental difficulties impossible to overcome, the mystery has not been solved. What is the composition of manure? That is about as

easy a question as "how old is Ann?" It cannot now be answered. Will it ever be possible to answer it satisfactorily? Who knows? What does manure do to the soil? How does it change the soil conditions and as a result the growth of the plant? Again, a Crop Science relationship appears! How shall manure be applied? When? How can it be conserved for application, when it must be stored? These are practical problems. Everyone knows the value of farm manure in bringing about increases in crop yields on most soils, but there are many unsolved mysteries involved in the effects of the manure and in the material itself! The bacterial life and action in farm manure and the occurrence of other micro-organisms make a series of mysteries which it will take many years of intensive work to unravel!

Then, too, the question arises, "Is organic matter necessary for the most economic crop production, for permanent soil fertility?" On the one hand, there is the evidence of centuries to show, practically, the value of applications of manure on crop production, and this value is assumed to be due mainly to the organic matter supplied, if not entirely so. On the other hand, the question may be asked, "Can soils be kept productive without manure?" It may also be asked, "What can the grain farmer, or the general farmer do, when there is no farm manure produced to apply to the land?" These latter questions have been answered practically by recommendations for the use of crop residues and leguminous green manures. Abundant evidence has been secured on the farm to prove the value of these sources of organic matter. But the question still unanswered is, "Can something else be done to keep soils productive without adding organic matter?" Future studies along this line will undoubtedly provide some evidence pro or con. At present, the maintenance of a supply of organic matter in soils is considered essential to permanent fertility! Suggestions to the contrary can have little practical support until data are available to prove the contention. We owe to posterity the obligation of standing for the fundamentals of permanent soil fertility and hence a permanent agriculture, according to the present evidence available—according to our lights! The mystery is not solved!

Then there are the problems of crop rotations and of the effect of one crop on another grown with it and on the succeeding crop. Are these Soils or Crops problems, you ask? Well, on the advice of counsel, I refuse to incriminate myself by giving a definite answer. Certainly the problems involve both sciences directly. They are important in many ways to soil questions. What are the effects of different crops on the soil? A mystery! What are the effects of ro-

tations, of varying rotations on the soil? Another mystery! When one crop grown on the land has a certain effect on the succeeding crop, what part does the soil play in the phenomenon? Again a mystery! Practically, we recommend certain rotations for special combinations of conditions, soil, climate, season, etc. We recommend certain special crops for some conditions. But these recommendations are based on the results secured *in crop yields* under particular experimental conditions. Can the results be guaranteed for other soil conditions? Do we know why? "No, we certainly do not!" It's a mystery!

Let us now turn to the problem of fertilizers and their use. This is such a vast problem, such an important subject that some believe it will become a science of itself. Perhaps so! But at present it is a part of both Crop Science and Soil Science and even if it does eventually become a separate individual science, it will still be of great significance to both sciences. But now it may be pointed out that there are a multitude of mysteries involved in the fertilizer problem, in the use of commercial fertilizers on land to increase productivity in an economical way and aid in keeping the soil permanently productive.

First of all, may I point out that the fertilizer program of the past has been centered around nitrogen, phosphorus, and potassium as the essential elements for plant growth, which are likely to be lacking in soils. But now numerous other elements are coming to be considered. Sulfur and calcium were added comparatively recently and at present we are giving careful thought and attention to certain other elements—some of which have previously not been deemed of any importance in plant growth. What elements should be supplied in a commercial fertilizer? It's a mystery! How about magnesium, manganese, iron, boron, iodine, and many other elements? Some investigations with certain elements indicate that we have only made a beginning in our studies of the constituents which should be added to soils commercially. We have only been gathering a few clues toward the solution of the mystery!

Then there is the question of testing soils or plants to determine the need for the addition of certain fertilizing materials. Many tests have been suggested. Some seem to give excellent results under certain conditions but refuse to work under other circumstances. The commercialization of the tests has speeded up work along this line, but it is still a mystery what tests should be devised to work under all conditions! The problem is still before us. Some progress is being made, but it is safe to say that no methods have yet appeared which

can be depended upon to give absolutely reliable results under all conditions! Why not? That's the mystery! Why do the results with different tests vary? Another mystery!

When the large number of commercial fertilizers on the market is considered, it becomes apparent that the problem of fertilizer use is an extensive one. What is the relative value of mineral nitrogen and organic nitrogen? What are the relative effects of various mineral forms and of different organic ammoniates? How do the synthetic products compare with natural materials? When and how and how much of the various materials should be used? These are all practical questions, not yet answered. But there are even more numerous technical questions involved. What are the effects on the soil of the various materials? Are the effects direct or indirect or partly direct and partly a result of a modification of soil conditions? Why do certain materials have particular observed effects?

The same questions may be asked regarding phosphorus, potassium, and complete commercial carriers. How about that old question, "Shall we use rock phosphate or superphosphate?" Has it been answered? Not yet! I speak of this question especially, as it has presented a problem for years and many of us have been under great pressure to secure an answer. It seems that an answer should have been secured. But one cannot yet be given! It's still a mystery!

In connection with phosphorus fertilization, I may also mention the problem of the effect of phosphorus carriers on the reaction of the soil and its need for lime. What changes in reaction, if any, are brought about by different phosphorus fertilizers? Do they have any neutralizing effect on acidity? There has been much talk of such an effect but little evidence. Now, we believe little or no neutralizing effect on acidity can be expected from phosphate additions. But future investigations may lead us to change our views. It's a mystery!

When potassium fertilizers are considered, there are many problems there. One may be mentioned as of particular interest now. Why do potassium fertilizers prove of value on high-lime and certain so-called "alkali" soils in the humid regions? These soils contain large amounts of total potassium. What has happened to the availability processes and to the potassium in those soils? Suggestions have been offered, but the real solution is still a mystery!

What complete fertilizers should be employed and when and how? We are securing data along these lines all the time—some of great significance. Great progress has been made but no answer can be given yet. It's still a mystery! High analysis versus low analysis materials, the exact formula to employ, the constituents in the fertil-

izer, home-mixing, the amounts to add to soils, broadcasting versus application in the hill, and how to secure a satisfactory application, are some of the problems under study, but they are not solved. Again we are gathering clues! But what are the effects on the soil of the different materials, variously applied? What is the reason for the influence on the crop? Is it a direct fertilization of the crop or is it a fertilization of the soil, of the rotation? Are these effects due to secondary influences (perhaps they should be considered primary) on the soil conditions? What are the residual effects, if any? What are they due to? It's all a mystery!

Perhaps I should also mention the effects of drainage, irrigation, cultivation, and other normal or special farming operations. The beneficial effects of removing excess water and of adding water when there is a deficiency are well known and primarily, practically, not at all mysterious. But the question here—and it's a mystery—is what is going on in soils that are too wet or too dry? What are the effects on the soils from drainage and irrigation? Then there are the questions, "Why cultivate corn and how often? What does the operation do to the soil along with the very obvious effect of reducing weed growth? How is the water content influenced? How are microbiological activities affected? What is the influence on the crop as a result of these effects? Why fall-plow? Why spring-plow? How about the depth of the seed bed? What are the effects of subsoiling, of rolling, of burning?" These are all mysteries!

Then the problem of erosion control and prevention should be mentioned. How serious erosion may be can only be estimated. It is so enormous that we are startled and appalled, but what are the effects on the individual farm? How can erosion be thoroughly controlled? How can it be prevented? What are the effects on the soil of such operations as terracing and other methods used in checking soil washing? How long will it take and what means can be employed to make a productive soil from a subsoil exposed by washing away of the surface soil? Many more questions regarding erosion and its control might be suggested. Much is being accomplished in a practical way, but the whole problem is still a mystery!

The problem of pastures should not be overlooked. How can permanent bluegrass pastures be maintained? What fertilizers should be employed? How should the pasture areas be handled? What about discing, reseeding, liming, fertilizing? When should the pasture be plowed up? These are all practical problems which have not yet been solved. We are making progress and some fine pasture experimental work is in progress. But it is a complex problem and is

still a mystery. From the technical side, many "whys" might be asked in connection with the pasture problem. There are numerous mysteries involved!

Enough has been said to make it quite apparent that there are literally hundreds, yes thousands of soil mysteries still remaining to be solved. Can there be any doubt regarding the mysterious nature of the soil, the important problem confronting us in the solution of the great mystery?

Why is there a soil mystery? This is a logical question which follows all that has been suggested. It is only comparatively recently that we have been finding out why. Of course, it has been known for a long time that soil was a complex material and hence might be expected to be filled with mysteries. But now we are coming to know soils as *soils*, to group and classify them on a more or less definite scientific basis which is rapidly becoming more and more definite and more and more scientific. The work of the soil survey, the mapping, classification, and study of soil characteristics carried out in connection with the survey, have enabled us to probe deeper into the mysteries of the soil and are providing a basis upon which a solution of the mystery can be reached. Of this we are confident! The fact that there are soil types, soil individuals as it were, has been established. True we do not yet have all the information we need on any of the types, but data are rapidly being accumulated and the development of Soil Science on a soil type basis is occurring with astonishing rapidity. The fact that there are soil types, definite in characteristics, occurring in certain areas, and under fixed conditions, but *differing from* all other soil types in many particulars, explains why there are so many mysteries in the soil as indicated in the previous discussion. Why should any soil treatment affect different soil types in the same way? It would be too much to expect. Why should it be assumed that the same results should be secured in any test where the soil type is not the same? It should not. The soil type may still be more or less of a mystery and it certainly is, but it is the mystery behind the big broad mystery of the soil, its management, and permanent fertility!

Much remains to be done on the study of soil types. The measurement of the physical characteristics of various types is proving a difficult problem. But it will be solved and exact physical descriptions will eventually be possible. Chemical studies are also providing problems which are requiring extensive work and we are still far from having methods entirely acceptable. They will come and exact chemical descriptions will be possible.

When we come to the microbiological factors involved in soil type separations, the situation is found to be even more complex, if that can be conceived of as possible. Microbiological studies have yielded information of great significance, but a start has hardly been made in the determination of the microbiological activities occurring in different soil types. We *know* literally nothing of the exact action of bacteria and other micro-organisms in the formation of soils, in the changes constantly occurring in soils during the formative period, after maturity, and in the old age, or period of decadence, of soils!

Along this line I may mention some of the outstanding mysteries which we find from a brief consideration of micro-organisms in soils and their activities. What organisms are present in different soil types? Why are certain species present? Why are others absent? These questions involve the problems of the source of the organisms, the development or lack of development in the particular soil, and the influence of all other soil conditions. There are also the influence of one group of organisms on another, the activities of the various organisms, and the efficiency of the organisms to be taken into account. What about the occurrence of molds, actinomyces, algae, and protozoa, as well as bacteria? Do they work together or in opposition? What is the effect of one group on another? How much anaerobic microbial action occurs in soils? Are there life cycles of the various organisms? What are the stages? What about spore formation, motility, multiplication, physiological efficiency of the different forms? Are there only a few species of nitrifiers? What do the aerobic non-symbiotic nitrogen fixers really do in soils? How about the action of the cellulose destroyers? What is the importance of the nitrate assimilators? What significance is connected with the sulfur oxidizers in various types? What relation do micro-organisms have to potassium, calcium, magnesium, iron, aluminum, and other elements? Does each micro-organism have one major function in soils or do they all participate in numerous activities? What about enzymes and their action in soils? And so on and on! There are certainly many mysteries here which must be cleared up before we shall have the necessary data to describe soil types properly from the microbiological standpoint.

Then we come back to a question similar to one suggested earlier in connection with the native vegetation on a soil. Are the bacteria and other micro-organisms present in soils and are their activities a result of soil type conditions or do the micro-organisms have an important part in the differentiation of types? We do not know! But we are convinced that micro-organisms have played and do play a vital

part in the formation of soils and hence of soil types and also in the development and aging of soils. What have they contributed? How have they acted? When and how did they become active? Speculation is rife on this point, but naturally this mystery cannot be solved except by deduction and ratiocination. Eventually this will be done! Until then it's a mystery!

It is obvious that the mysteries of the soil type, physical, chemical, and biological, are extremely numerous and I have not even mentioned colloids, base exchange, and a host of other "family pets." All the mysteries are being solved one by one and the work of the future will bring many more solutions. The classification of soils into types is fundamental to the rational development of Soil Science. The solution of the soil type mysteries will provide basic clues to the solution of the big mystery of the soil itself, to the clearing up of the mysteries involved in soil management, permanent soil fertility, and a permanent agriculture!

All this may seem a dark, depressing, even pessimistic discussion. It has not been so intended. You may be thinking that I am merely suggesting the vast number and great importance of the things we do not know about soils and Soil Science! It may seem that I have overlooked all that has been done and all that we know now! That is far from my intention!

I would not for a moment give the impression that the work which has been done is not important. It is! May I reiterate the statement that probably no other science has made such rapid progress as has Soil Science There is already a vast collection of clues piling up, as a result of the extensive studies under way and these will eventually lead to the solution of all the mysteries.

But I cannot provide the conclusion to this soil mystery, such as is always expected and given in mystery novels. The murderer is found, usually the most unlikely person. The strange occurrences, the distracting clues, the false scents, the fantastic theories are all readily explained. The innocent suspect is freed and lives happy ever after! The death of the victim is avenged—the murderer pays the penalty! "Crime does not pay."

Eventually the mystery of the soil will be solved. But it will not be in my time or yours! Great progress is being made! Already the crime of killing the poor old man "Soil" has been found not to pay! The murderers are finding this out! It is becoming a recognized fact that good soil management pays! To keep the old man alive and vigorous is now quite the thing! Farmers are actually becoming "soil conscious." They are recognizing that the soil is their one

great asset and the basis of all their operations, of their success or of their failure! All people are coming to a realization that the soil is the national resource of the land which must be conserved to permit of a future agriculture, a future adequate production of food for the human race!

It is up to us to do all that we can to solve the mystery of the soil in order that we may have proper and adequate soil management practices and that the great natural resource of our country may be conserved for the support of future generations!

Agronomists, soils and crops specialists, it is up to you to continue to develop your studies along all these lines in order to hasten the arrival of the denouement of the great mystery! It will come! Of that we can be sure! No disappointments or discouragements, no futile disagreements or discussions should be permitted to take our attention from the desired goal! There is an infinite amount of work to be done. There are many clues to be traced! Our goal is the solution of the mystery of the Soil! Let us push on!

AN EXPERIMENTAL STUDY OF THE ROD-ROW METHOD WITH SPRING WHEAT[1]

H. K. HAYES, H. K. WILSON, and E. R. AUSEMUS[2]

The first extensive use of the rod-row method for obtaining comparative data on yield and other characters of small grains was made by J. B. Norton of the U. S. Dept. of Agriculture. In many cases rod rows are spaced a foot apart which is about twice as great space as obtained from the ordinary grain drill. The rod-row method is con-

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. This is a phase of the wheat studies conducted cooperatively by the Minnesota Agricultural Experiment Station and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Paper No. 1089 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication April 18, 1932.

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venient and, according to Montgomery[3] and Love and Craig,[4] it is a reliable means of obtaining comparable trials of varieties.

Various rates of seeding have been used. The Washington Agricultural Experiment Station sows 150 seeds per row. Others sow at the same rate per unit area of length as is used for each row under field methods of planting with the field grain drill. In many cases 1½ to 2 times as much seed is used per row as is commonly sown in the same length of row under field methods. With this plan rates of seeding per acre do not differ materially in rod-row trials and in field plats. Seeds of grain varieties differ materially in size and weight. Some investigators have corrected on the basis of grain size and sow an equal number of kernels per unit area, although the more general plan is to sow an equal weight or volume of grain per row. With the great importance of the rod-row trial in small grain breeding, it appears strange that more tests have not been made of its reliability. The purpose of the study reported here was to compare various rates and methods of seeding spring wheat in rod-row trials in order to determine the most desirable technic.

EXPERIMENTAL METHODS AND RESULTS

Studies have been continued for a 3-year period, although somewhat different methods were used each of the 3 years. For this reason it appears to be desirable to give the technic employed and results obtained independently for each year.

1926 STUDIES

The four varieties used in the study were selected because of wide differences in normal grain weight. The seed was carefully fanned and only plump grains used. The weight in grams of 1,000 seeds and the varieties selected are as follows: Marquis, 28.7; Marquis x Kanred, II-17-40, 31.4; Kota Natural Cross, II-19-2, 25.9; Mindum, 45.0. The purpose of the study was to compare rates of seeding in rod-row plats spaced 1 foot apart. Three rows were used for each plat and 16 feet of the central row only were harvested. For a standard of comparison two methods of seeding in rows 6 inches apart were used. It was thought that this would be similar to field methods of seeding. For the rows which were 6 inches apart, six-row plats were used and the two central rows harvested.

[3]MONTGOMERY, E. G. Experiments in wheat breeding. U. S. D. A. Bur. Plant Ind. Bul. 269. 1913.

[4]LOVE, H. H., and CRAIG, W. T. Method used and results obtained in cereal investigations at the Cornell Station. Jour. Amer. Soc. Agron., 10: 145-157. 1918.

The usual rate of seeding for wheat rod rows in Minnesota is 19.8 grams per 18 square feet of area. The amount sown in each row for the corrected rate was obtained by multiplying 16.8 by the weight of 1,000 seeds for the variety concerned and dividing by the average weight of 1,000 seeds for the four varieties. The purpose of this correction was to obtain the same number of seeds per row. Thus the corrected weight for Mindum per 18-foot row was $\frac{16.8 \times 44.95}{30.79}$ = 24.5. For half this rate of seeding, 24.5 was divided by 2.

Furrows were opened with a wheel hoe and the seed scattered by hand. The rows in A to E were spaced 1 foot apart, while those of F and H were spaced 6 inches apart and all rows were 18 feet in length. The rate of seeding was as follows:

A, 200 seeds per row.
B, 8.4 grams per row.
C, Same average rate as B, corrected for kernel weight; seeding rate, Marquis, 7.8 grams; Marquis x Kanred, 8.6 grams; Kota Nat. Cross, 7.0 grams; Mindum, 12.3 grams.
D, 16.8 grams per row.
E, Same average rate as D, corrected for kernel weight; seeding rate twice that given under C.
F, 8.4 grams per row.
H, Same average rate as F, corrected for kernel weight; seeding rate per row the same as C.

A systematic arrangement of the plats in each replication was used and seven plats were grown for each treatment. Separate probable errors were computed for each variety and rate of planting. Mean yields are given in Table 1.

TABLE 1.—*Average yields in bushels per acre for various rates of seeding of the varieties Marquis, Marquis x Kanred, Kota Natural Cross, and Mindum.*

Rate of planting	Distance of rows apart	Variety and yield in bu. per acre			
		Marquis	Marquis x Kanred	Kota Natural Cross	Mindum
A, 200 seeds per row	1 foot	22.1±1.9	27.4±2.1	25.3±1.8	31.8±1.1
B, 8.4 grams per row	1 foot	23.7±1.5	27.3±1.4	25.0±1.3	28.7±1.6
C, Similar to B, corrected	1 foot	23.9±1.2	—	27.4±1.5	29.7±3.1
D, 16.8 grams per row	1 foot	26.9±1.0	35.8±1.6	29.8±1.6	36.7±3.0
E, Similar to D, corrected	1 foot	24.9±1.0	—	28.1±1.3	34.0±3.3
F, 8.4 grams per row	6 inches	29.7±1.5	31.6±0.9	30.6±1.6	31.0±2.4
H, Similar to F, corrected	6 inches	31.8±1.2	—	31.5±1.6	33.3±1.8

Calculated corrections for Marquis x Kanred gave no appreciable change in rate of seeding and rates C, E, and H were not planted.

Black stem rust was prevalent, the infection being most severe in Marquis and least damaging in Mindum and Kota Natural Cross. As such conditions are frequent for spring wheat in Minnesota, it adds to the interest to have a part of the studies under such severe conditions.

Certain general conclusions can be drawn from the experiment. Yields of each of the two common wheats were considerably higher for rates of sowing D, E, F, and H than for A, B, and C. If maximum yields are desired, then a heavy rate of sowing appears superior to a light rate.

Mindum, the variety with the largest average weight of grain, received no benefit, on the average, by using a rate of sowing which was corrected to the same number of seeds per row. In fact, lower but not significantly different yields were obtained from the corrected than from the standard rate of sowing. The corrected rate appeared unnecessary under the seasonal conditions of 1926.

1927 RESULTS

The same four varieties were used as in 1926. The average weights of 1,000 seeds in grams of the varieties were as follows: Marquis, 29.5; Kota Natural Cross II–19–2, 27.0; Marquis x Kanred, II–17–40, 31.9; and Mindum 39.1. The same rates of planting were used as in 1926 and in addition the amounts of seed used for each rate of planting were corrected on the basis of a germination trial. The germination percentages of the four varieties were Marquis, 83; Marquis x Kanred, 86.5; Kota Natural Cross, 88.5; and Mindum, 68. The rates of seeding for methods C, E, and H were corrected for kernel size (Table 2)

TABLE 2. —*Methods and rates of seeding of the varieties Marquis, Marquis x Kanred. Kota Natural Cross, and Mindum in 1927.*

Method of seeding	Distance between rows	Variety and rate of seeding			
		Marquis	Marquis x Kanred	Kota Natural Cross	Mindum
A...........	1 foot	241 seeds	231 seeds	226 seeds	294 seeds
B...........	1 foot	10.1 grams	9.7 grams	9.5 grams	12.4 grams
C...........	1 foot	9.4 grams	9.7 grams	8.0 grams	15.1 grams
D...........	1 foot	20.2 grams	19.4 grams	19.0 grams	24.7 grams
E...........	1 foot	18.7 grams	19.4 grams	16.0 grams	30.3 grams
F...........	6 inches	10.1 grams	9.7 grams	9.5 grams	12.4 grams
H...........	6 inches	9.4 grams	9.7 grams	8.0 grams	15.1 grams
K (Marquis check)....	6 inches	10.1 grams	10.1 grams	10.1 grams	10.1 grams

The seven rates of seeding for each variety and the Marquis check were grouped in a Latin square arrangement which contained 56 plats of the variety and eight Marquis checks. One plat of each rate of seeding and the Marquis check appeared at random in each row and column with the exception that the same treatment did not appear in adjacent rows or columns.

The planting arrangement for each variety and for the Marquis check was as follows:

VIII	E	K	C	H	F	B	A	D
VII	H	A	K	D	C	E	B	F
VI	C	F	H	B	E	A	D	K
V	K	C	E	A	D	H	F	B
IV	B	D	A	F	K	C	H	E
III	A	B	D	K	H	F	E	C
II	F	E	B	C	A	D	K	H
I	D	H	F	E	B	K	C	A

Calculations of variance due to rows, columns, treatment, Marquis vs. treatment, and totals were made and a comparison drawn between varietal variability and uncontrolled error according to the method of analysis as outlined by Fisher.[5] Both leaf rust and stem rust infection were severe and other conditions were not especially favorable.

The analysis of variance takes the following form for the four Latin square trials:

	Degrees of freedom	Sums of squares	Calculated variance	½ $\log_e$	Difference $=Z$
		Marquis			
Columns	7	85.9500			
Rows	7	66.7300			
Treatment	6	288.4321	48.0720	1.9363	
Marquis vs. treatment	1	120.1429			
Remainder	42	191.6950	4.5642	.7591	1.1772
Total	63	752.0500			

[5]Fisher, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 3. 1930.

	Degrees of freedom	Sums of squares	Calculated variance	½ loge	Difference =Z
		Marquis x Kanred			
Columns	7	137.9094			
Rows	7	102.0694			
Treatment	6	416.6093	69.4349	2.1202	
Marquis vs. treatment	1	0.0201			
Remainder	42	240.2312	5.7198	.8720	1.2482
Total	63	896.8394			
		Kota Natural Cross			
Columns	7	73.3775			
Rows	7	182.6025			
Treatment	6	662.5586	110.4264	2.3513	
Marquis vs. treatment	1	29.0089			
Remainder.	42	295.1500	7.0274	.9749	1.3764
Total	63	1242.6975			
		Mindum			
Columns	7	305.8788			
Rows	7	48.6363			
Treatment	6	108.8786	18.1464	1.4492	
Treatment vs. Marquis	1	1668.6002			
Remainder	42	593.9363	14.1413	1.3245	0.1247
Total	63	2725.9302			

The value of Z at the 1% point for an n_1 and n_2 of 6 and 30, respectively, given in Fisher's table[6] is .6226. The calculated values of Z for a comparison of variance due to remainder and that for treatment with the varieties Marquis, Marquis x Kanred, and Kota Natural Cross are approximately 2 times .6226, so we may conclude that the differences in yield with each of the three varieties of bread wheat due to rate of seeding were highly significant. With Mindum, however, the variation in yield due to rate of seeding was not significant, mathematically.

The average yields given in each of the four Latin squares and the probable error in percentages for the use of eight plats are given in Table 3. The probable errors of a single determination were calculated from remainders in each case.

TABLE 3.—*Average yields of the four Latin squares and the generalized probable errors in percentages of the mean.*

Latin square containing	Yield in bushels	P. E. in % for mean of 8 plats
Marquis	15.36	3.32
Marquis x Kanred	17.55	3.25
Kota Natural Cross	19.61	3.22
Mindum	32.02	2.80

The average yield in bushels for each rate of planting was multiplied by the generalized probable error in percentage for the Latin square

[6] *Loc. cit.*

in which the test was conducted. Yields for the various treatments with their respective probable errors are given in Table 4.

TABLE 4.—*Yields in bushels per acre for various rates of Marquis, Marquis x Kanred, Kota Natural Cross, and Mindum, when sown in Latin squares.*

Method of seeding	Marquis	Marquis x Kanred	Kota Natural Cross	Mindum
A	12.00±.40	12.86±.32	13.11±.42	32.29± .90
B	13.04±.43	15.74±.51	17.84±.57	32.34± .91
C	13.10±.43	16.31±.53	18.16±.58	34.09± .95
D	14.81±.49	17.70±.58	22.33±.72	35.14± .98
E	14.83±.49	18.10±.59	21.18±.68	34.66± .97
F	17.41±.58	21.19±.69	23.45±.76	32.91± .92
H	18.73±.62	20.98±.68	22.96±.74	36.24±1.01
K* (Marquis check)	18.99±.63	17.50±.57	17.83±.57	18.51± .52

*This row gives the yield of the Marquis check in the four Latin squares.

The yield of the Marquis check K gives a comparison of yielding ability in the four Latin squares. The differences in yield of the Marquis checks are very small in the light of their probable errors. Each of the seven methods of seeding places the four varieties in the same order in yield, i. e., Mindum first; Kota Natural Cross, second; Marquis x Kanred, third; and Marquis, fourth.

With the three bread wheats, the rates of seeding D and E, i. e., the same rates as used in field plats, gave a higher yield than when a lighter seeding was used as in methods A, B, and C.

Accepting methods F and H as standards because they closely approach the method of the farmer in which case the material was grown in rows spaced 6 inches apart, it is apparent that methods D and E are more reliable than methods A, B, and C.

Mindum, the durum variety which suffered less because of unfavorable conditions, tended to yield about the same at all rates of seeding.

From the results of the two years' study it appears that varieties such as Marquis and Marquis x Kanred which were injured most severely by rust might be expected to show wider differences in yield in rod-row trials than when grown in rows spaced 6 inches apart. It is possible that moisture conditions were more favorable in the 6-inch rows.

1929 RESULTS

The methods of conducting the studies in 1929 were modified to some extent. Seventeen varieties of wheat selected to test in the 1/40-acre varietal plats were sown in rod-row trials on the same day (April 26) as the regular 1/40-acre variety trial and on the same field.

Only four methods of seeding were practiced in the row trials, three of these being sown with a Columbia planter, the fourth being sown by hand. The drill was calibrated by turning the drive wheel 10 rounds and then weighing the seed dropped. Plate A 12 was used in all cases except for the regular and corrected rates of sowing for the variety Marquis x Emmer 2301. With this variety Plate A 5 was used. Method C was corrected on the basis of grain weight in much the same manner as in previous years. The four methods of seeding were as follows:

A, 16.8 grams with drill.
B, 8.4 grams with drill.
C, Regular rate (16.8 grams) corrected for grain weight, with drill.
D, 16.8 grams by hand in rows opened with wheel hoe and then covered by hand.

The 17 varieties of wheat used in the study and the corrected weights of seed sown per row (C) are given in Table 5.

TABLE 5.—*Weight of 200 kernels and the corrected weight of seed in grams seeded per row under Method C.*

Variety	Minn. No.	Weight of 200 kernels, grams	Regular rate corrected for seed size, grams
Marquis	1,239	6.73	17.9
H-44	2,301	6.57	17.5
Double Cross	2,303	5.77	15.4
Marquillo	2,202	7.15	19.0
Reward	2,204	6.62	17.6
Supreme	2,309	5.73	15.3
Kota x Marquis	2,224	5.77	15.4
Ceres	2,223	6.74	17.2
Double Cross	2,305	6.42	17.1
Double Cross	2,304	7.22	19.2
Reliance	2,308	6.44	17.5
Kota x Marquis	2,244	6.28	16.7
Hope	2,279	5.90	15.7
Progress	2,225	6.86	18.3
Double Cross	2,302	6.36	16.9
Kota x Marquis	2,298	6.19	16.5
Bluestem	160	4.75	12.7

These varieties were grown in rod-row trials and each of the four methods of seeding was practiced. Each variety and rate of seeding were sown in six systematically distributed three-row plats. The four rates of seeding of each variety were grouped. Sixteen feet of the central row of each plat were harvested and the yields given are an average of the six plats. Also, each variety was sown with a horse-drawn grain drill in three systematically distributed 1/40-acre plats.

The two outside border rows and 1 foot from each end were removed from each 1/40-acre plat before harvest.

Generalized probable errors were computed separately for each of the five methods of seeding by the use of the deviation of the mean method where P. E. of a mean $= \pm .6745\sqrt{\frac{S\ (d)^2}{N\ (n-1)}}$. In this formula d = the deviation of each plat of a variety and rate of seeding from its mean, N = total deviations, and n = number of replications.

Probable errors in percentage were computed by dividing the probable error in bushels by the average yield of the varieties in the particular method of seeding tested. Probable errors in percentage for the five methods of treatment are given in Table 4.

TABLE 4.—*Probable errors in percentage for six systematically distributed rod-row plats and three systematically distributed 1/40-acre plats.*

Method of treatment	P. E. in %
A, Rod rows, 16.8 grams sown with drill	4.34
B, Rod rows, 8.4 grams sown with drill	4.75
C, Rod rows, regular rate (16.8) corrected for seed size, sown with drill	4.71
D, Rod rows, 16.8 grams sown by hand	3.67
E, 1/40-acre plats	4.09

The yields of the varieties in the trials and their probable errors are given in Table 5.

TABLE 5.—*Yield in bushels per acre of 16 varieties of wheat grown under five different methods of seeding.*

Variety	Minn. No.	Method of seeding				
		Rod rows				1/40-acre plats
		A	B	C	D	E
Marquis	1,239	26.2±1.1	25.6±1.2	28.4±1.3	26.3±1.0	34.3±1.4
Marquis x Emmer	2,301	29.4±1.3	24.3±1.2	28.9±1.4	27.1±1.0	34.3±1.4
Double Cross	2,303	26.1±1.1	23.2±1.1	25.2±1.2	27.5±1.0	31.1±1.3
Marquillo	2,202	26.0±1.1	22.2±1.1	25.5±1.2	27.7±1.0	34.5±1.4
Reward	2,204	26.8±1.2	21.1±1.0	24.7±1.2	26.1±1.0	28.8±1.2
Supreme	2,309	29.6±1.3	25.7±1.2	26.8±1.3	24.8±0.9	33.2±1.4
Kota x Marquis	2,224	30.2±1.3	28.1±1.3	28.9±1.4	28.6±1.0	31.6±1.3
Ceres	2,223	28.3±1.2	23.9±1.1	26.9±1.3	27.1±1.0	33.2±1.4
Double Cross	2,305	30.3±1.3	26.1±1.2	32.7±1.5	26.6±1.0	33.4±1.4
Double Cross	2,304	27.3±1.2	24.4±1.2	27.3±1.3	29.0±1.1	32.4±1.2
Reliance	2,308	34.1±1.5	27.6±1.3	32.1±1.5	31.6±1.2	38.6±1.6
Kota x Marquis	2,244	32.9±1.4	28.5±1.4	33.5±1.6	31.1±1.1	31.3±1.3
Hope	2,297	26.0±1.1	26.1±1.2	26.7±1.3	24.6±0.9	29.6±1.3
Progress	2,225	28.1±1.2	23.5±1.1	27.8±1.3	25.9±1.0	
Double Cross	2,302	24.5±1.1	23.7±1.1	27.0±1.3	23.1±0.8	31.7±1.3
Kota x Marquis	2,298	27.1±1.2	23.4±1.1	29.8±1.4	29.5±1.1	33.6±1.4
Bluestem	169	27.7±1.2	25.4±1.2	24.9±1.2	22.5±0.8	27.8±1.1
Average without Progress	—	28.3	25.0	28.1	27.1	3.25

The yields of the 16 varieties that were grown in the five different methods of seeding were used in computing correlation coefficients to express the degree of association obtained by the different methods. The correlation coefficients obtained are summarized in Table 6.

TABLE 6.—*Correlation between the yields of 16 varieties of wheat when grown under five different methods of seeding.*

Method	B	C	D	E
A	.7182	.7593	.6153	.4483
B	—	.6852	.2782	.1770
C	—	—	.6253	.5207
D	—	—	—	.5605

The values of the correlation coefficient at different levels of significance for an n of 14 (2 less than sample) as given by Fisher[7] and for the different values of P of .1, .05, .02, and .01 were .4259, .4973, .5742, and .6226, respectively. The lowest correlations on an average were obtained for the relationship between half the regular rate sown with the grain drill and the other methods of seeding.

Methods A and C, sown with the grain drill at the rate of 16.8 grams per row and the same rate corrected for differences in average kernel weight, respectively, gave about the same values of the correlation coefficient when correlated respectively with the different methods of seeding. The correlation coefficient between methods A and C was .7593. Three possible correlation coefficients were calculated for inter-relations between yields obtained by the three methods of seeding in rod-row trials or A, C, and D. Calculated coefficients were .7593, .6153, and .6253, respectively, or an arithmetical average of .6667. Correlation coefficients between the yields obtained by the methods of seeding in rod-row trials A, C, and D, and the yield obtained in the 1/40-acre plats or method E, were .4483, .5207, and .5605, respectively, or an arithmetical average of .5098. These relationships may seem rather small to the reader. It should be recognized, however, that the size of a correlation coefficient depends to a large extent on the nature of the material in the trial. The 16 varieties in the trial represent for the most part highly selected varieties of wheat. In a season in which rust was not a factor and other conditions were favorable, all varieties used in the study have ability to give excellent yields. This fact may be emphasized by noting that the lowest yield obtained in the 1/40-acre plats was 27.8 bushels for Bluestem. If varieties had been used in the studies which deviated more widely in yielding ability, larger correlation coefficients probably would have been obtained.

[7]*Loc. cit.*

SUMMARY AND CONCLUSIONS

1. It appeared unnecessary with spring wheat to correct the rate of seeding in rod-row trials on the basis of differences in average kernel weight.

2. At University Farm, St. Paul, Minn., the hand method of sowing rod rows appeared to be slightly superior to the drill method, although the differences obtained were very small and perhaps due only to chance. The drill method of seeding was considered satisfactory and is being used at Minnesota.

3. The trials made in 1926 and 1927 at University Farm, St. Paul, indicate that a heavy rate of seeding in rod-row trials was more satisfactory than a lighter rate. The comparison of yields in rod-row and in 1/40-acre plats was conducted in only a single season and with a group of highly selected varieties. The results obtained gave further evidence in favor of the heavier rate of seeding.

LINKAGE RELATIONS OF A SECOND BROWN MIDRIB GENE (bm_2) IN MAIZE[1]

C. R. Burnham and R. A. Brink[2]

The brown midrib (bm_2) character under discussion appeared among the offspring of a plant of the Golden Glow variety of corn in the first generation of selfing. It is similar in appearance to the brown midrib (bm_1) described by Eyster (3)[3] and Jorgenson (5), but distinct from it genetically as shown by the intercross. The brown coloration is visible externally in the midrib of the leaf and over the vascular bundles of the leaf sheath. Free-hand sections show that the pigment is present in the sclerenchyma or lignified tissue over the vascular bundles. Whether or not it is present in all of the cellulose walls has not been determined, but it is most pronounced in the thicker-walled cells.

The character may begin to appear in seedlings at the three- or four-leaf stage but is more easily recognized later. It can be readily distinguished in the presence of any of the combinations of the fundamental color factors *A*, *B*, and *Pl* and their allelomorphs if classifi-

[1]Papers from the Wm. G. Kerckhoff Laboratories, California Institute of Technology, and the Department of Genetics, Agricultural Experiment Station, University of Wisconsin, No. 132. Published with the approval of the Director of the Station. Received for publication April 25, 1932.

[2]Fellow of the National Research Council and Professor of Genetics, respectively.

[3]Reference by number is to "Literature Cited," p. 963.

cation is made before the plants are in tassel. Beyond this stage of development the brown midrib color may be obscured in full purple plants by the intense anthocyanin pigment. Clear-cut separation in these cases, however, may be made by examining free-hand sections of the midribs under a microscope.

The character is inherited as a simple recessive. Out of 16,784 plants from Bm_2bm_2 individuals selfed, 3,684 were brown midrib, a deviation from a 3:1 ratio of 512 ± 38. From backcrosses of heterozygotes to brown midrib out of 4,295 plants, 2,053 were brown midrib, a deviation from equality of 94 ± 22. The deficiencies of brown midrib plants appear to be statistically significant, but their cause is not known. The brown midrib plants are not visibly weaker than their normal sibs.

Linkage tests were made with factors in most of the groups (Table 1), including *P* and *f* in the *P-br* group, without at first finding any certain evidence of linkage. Percentages of recombination and probable errors were calculated on the basis of Immer's (4) tables, and a modification of Owen's (6) tables. Certain of the deviations are large, but only that with *f* is significant, $\frac{\text{Dev.}}{\text{P.E.}}$ being 3.8. Back-cross tests gave a higher cross-over value with *f*, namely, 45.2%. Evidence of linkage was obtained also with semi-sterile-1, 40.8% crossing over being found, according to Brink and Cooper (1). This is a loose linkage, but different cultures were consistent in showing less than 50% recombination. On this basis, bm_2 appeared to be in either the *B-lg* or the *P-br* group, since semi-sterile-1 involves these two groups (Brink and Cooper, 1). Subsequent studies have shown bm_2 to be linked with semi-sterile-3 (involving *P-br* and gl_1ra) and with semi-sterile-5 (involving *P-br* and *Y-Pl*) with about 35% of crossing over in each case (unpublished data). Since it is the *P-br* chromosome which is concerned in all three of these semi-steriles, bm_2 must be located in the *P-br* group.

Further evidence in this direction was obtained from trisomic tests with bm_2. The trisomic (2n + 1) type for *P-br* was not available for a direct experiment, but tests with stocks trisomic for the *B-lg* and gl_1ra chromosomes, respectively, gave ordinary disomic ratios. This confirms the conclusion that the linkage with semi-steriles-1 and -3 is due to the presence of bm_2 in the *P-br* chromosome.

Direct genetic tests were made with other factors in this chromosome (Table 2). The 26.9% recombination with *gs* shows definitely that bm_2 is located in the *P-br* group. A back-cross test of semi-sterile-1 with *gs* gave 117 semi-steriles and 7 normals in the *Gs* class.

This is equivalent to 5.6% recombination. The *gs* offspring were not classified. These data, together with those reported by Brink and

TABLE 1.—*Linkage tests of bm_2 with factors in the different linkage groups.*

Linkage group	Gene	Linkage phase	X Bm_2	X bm_2	x Bm_2	x bm_2	Total	Recombination %
A-d_1	*A*	F_2 R	409	109	136	40	694	51.5
	ts_4	F_2 R	290	109	136	33	568	44.0
	cr	bkc R	48	39	46	29	162	47.5
	d_1	bkc R	157	137	148	124	566	50.4
su-Tu	Tu*	F_2 C	242	66	63	16	387	51.0
	su	F_2 R	353	93	167	38	651	48.0
B-lg	*lg*	bkc R	116	110	120	121	467	49.3
	B	F_2 R	627	178	194	46	1,045	52.5
	v_4	F_2 R	291	72	69	20	452	57.5
pr-v_2	*pr*	bkc R	88	72	89	84	333	48.4
	bt	F_2 R	291	78	128	41	538	52.5
	v_2	F_2 R	167	61	42	13	283	47.7
Y-Pl	*Y*	F_2 C	360	99	234	70	763	51.0
	Pl	F_2 C	193	49	69	26	337	44.5
	al†	F_2 R	108	29	22	4	163	44.5
ra-gl_1	*ra*	F_2 R	655	179	236	66	1,136	50.5
	ij	F_2 R	754	191	118	39	1,102	53.7
C-sh-wx	*sh*	F_2 R	607	165	322	91	1,185	50.5
	wx	F_2 R	471	131	274	90	966	52.5
r-g_1	*R*	F_2 C	557	175	372	81	1,185	55.2
	g_1	bkc R	58	51	56	55	220	51.4
Miscellaneous	*j*	F_2 R	888	266	231	58	1,443	47.5
	g_2	F_2 R	315	85	75	20	495	49.0

*Hom. *Tu* and *Tu tu* plants were classified.
†Albescent.

Cooper (1), indicate that the probable order of the genes is *P-br-f-an-gs-bm_2* with *ad* not definitely placed. The linkage relations are depicted in Fig. 1.

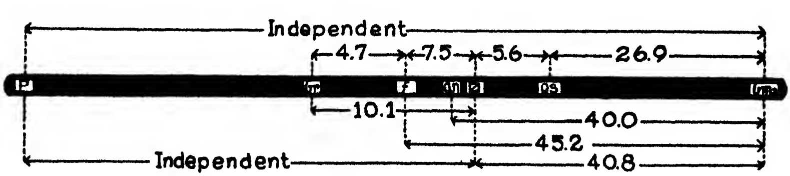

FIG. 1.—Chromosome map showing the position of brown midrib (bm_2) in relation to other genes known to be in the *P-br* group and to a translocation involving this chromosome. The cross-over values shown are all based on backcross data.

TABLE 2.—*Linkage tests of bm_2 with factors in the P-br linkage group.*

Gene	Linkage phase	X Bm_2	X bm_2	x Bm_2	x bm_2	Total	Recombination %
P	bkc C*	45	47	39	44	175	50.9
f	F_2 R†	168	57	73	10	308	37.4
	bkc R‡	267	304	257	195	1,023	45.2
an	F_2 R	669	216	171	12	1,068	29.5
	bkc R	259	351	368	221	1,199	40.0
gs	F_2 R	341	145	121	2	609	13.6
	bkc R	152	334	344	98	928	26.9
ad	F_2 R	584	195	213	47	1,039	44 3

*Back-cross, coupling phase.
†F_2, repulsion phase.
‡Back-cross, repulsion phase.

The discovery of bm_2 at a point in the chromosome remote from *P* and *f* greatly extends the length of the map of this chromosome. This is significant, since cytologically *P-br* is the longest chromosome (Burnham, 2). In order to cover this chromosome adequately in genetic tests it is apparent now that at least three factors must be used.

SUMMARY

A second brown midrib character in maize is described. The brown midrib gene (bm_2) is located in the *P-br* group, the probable order of the factors tested being *P-br-f-an-gs-*bm_2. The location of bm_2 in this chromosome at a point remote from *P* and *f* greatly extends the map of the group.

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USE OF THE YIELD EQUATION IN PINEAPPLE CULTURE[1]

C. A. FARDEN and O. C. MAGISTAD[2]

In a previous article (1),[3] we have presented data on the yield of pineapples as influenced by potash fertilization. The results obtained were subjected to mathematical treatment in which the constants in the yield equation, $Y = M - AR^x$, as proposed by Spillman and Lang (3), were determined. A method termed "Spillman's second method," of evaluating the constants was presented. By means of the yield equation, it was shown how the amount of available plant food, potash, in the soil might be determined.

The purpose of the present paper is to present the application of the yield equation to determine the economical limit of fertilization with changing prices of fertilizers. Inasmuch as the method presented in the previous article (1) for determining the constants in the yield equation $Y = M - AR^x$ require calculating equipment not available to many, it seemed well to include in this paper a simpler method for the determination of these constants.

METHOD OF DETERMINING CONSTANTS IN THE YIELD EQUATION

The harvest results with varied potash fertilization previously presented (1) are reproduced in Table 1 for convenience.

TABLE 1.—*Harvest results showing smaller increase in fruit weight with each additional unit of fertilizer*

x, units of potash	Pounds per acre of potash	Tons of pineapple per acre	Y, tons of pineapple gained for each additional 100 lbs. of potash
	Plant Crop		
1	100	15.65	1.62
2	200	17.27	0.90
3	300	18.17	0.41
4	400	18.58	—
	Cycle Crop		
0.	220	39.20	3.24
1	320	42.44	2.92
2	420	45.36	1.52
3	520	46.88	—

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[3]Reference by number is to "Literature Cited," p 975.

The field experiment for the plant crop did not include a plat having lx units of potash and the corresponding yield was obtained by interpolation, which gave 15.65 tons per acre. The practice of supplying missing values by interpolation is very undesirable as the choice of a value here always leaves the final yield equation open to question. The method is easily applied when the quantity of fertilizer used on each plat can be expressed in units of 1x, 2x, 3x, 4x, as they occur in Table 1.

The method is given by Spillman and Lang (3, page 15) and by Spillman (4). It is developed below in essentially the same manner but substituting actual yields, Y, in place of yield increases, y.

Let Y = yield of pineapples due to x units of fertilizer, and x = units of fertilizer applied per acre.

If x increases by an increment Δ x, then Y will increase by Δ Y; hence Y + Δ Y = yield due to x + Δ x units of fertilizer.

$$Y = M - AR^x \qquad 1$$

But $Y = M - AR^x$ 1

Therefore, $Y + \Delta Y = M - AR^{x+\Delta x}$ 2

Subtracting 1 from 2,

$$\begin{aligned} \Delta Y &= AR^x - AR^{x+\Delta x} \\ &= AR^x (1 - R^{\Delta x}) \qquad 3 \end{aligned}$$

If Δ x represents differences of 1 unit of fertilizer, then Δ Y will represent increases between yields due to unit differences of fertilizer; hence $\Delta Y = AR^x (1 - R)$.

Taking logarithms, $\log \Delta Y = x \log R + \log A (1 - R)$ 4

We now apply equation 4 to the data of the plant crop given in Table 1 in the following manner:

$$\begin{array}{rcrcl} \log \Delta Y & = & \log \Delta Y & = & x \log R + \log A (1 - R) \\ \log 1.62 & = & 0.2095 & = & 1 \log R + \log A (1 - R) \\ \log 0.90 & = & -0.0458 & = & 2 \log R + \log A (1 - R) \\ \log 0.41 & = & -0.3872 & = & 3 \log R + \log A (1 - R) \\ \hline \text{Total} & & -0.2235 & = & 6 \log R + 3 \log A (1 - R) \qquad 5 \end{array}$$

Equation 5 is termed the "normal" equation for log A (1 — R).

We next obtain a normal equation for log R by multiplying each of the original three equations by the coefficient of log R in that equation and add as follows:

$$\begin{array}{lcrcl} 1 \text{ x } 0.2095 & = & 0.2095 & = & 1^2 \log R + 1 \log A (1 - R) \\ 2 \text{ x } (-0.0458) & = & -0.0916 & = & 2^2 \log R + 2 \log A (1 - R) \\ 3 \text{ x } (-0.3872) & = & -1.1616 & = & 3^2 \log R + 3 \log A (1 - R) \\ \hline \text{Total} & & -1.0437 & = & 14 \log R + 6 \log A (1 - R) \qquad 6 \end{array}$$

Equation 6 is the normal equation for log R. The two normal equations thus obtained are:

$$-0.2235 = 6 \log R + 3 \log A (1 - R)$$
$$-1.0437 = 14 \log R + 6 \log A (1 - R)$$

Solving these by elimination, we find $\log R = -0.2984$, whence $R = 0.503$, and $\log A (1 - R) = 0.5223$, whence $A = 6.70$ tons.

Substituting these values of R and A in equation 1, we have $Y = M - 6.70 (0.503)^x$ in which M is still undetermined. This is determined by taking the average of the M values obtained by substituting for x and Y the series of values found in the first and second columns of Table 2. The average M value obtained in this manner is 19.00.

TABLE 2.—*Table of values of Y, AR^x, and M for the plant crop.*

Units x	Actual yields Y	Possible increase AR^x	Maximum yields M
1	15.65	3.37	19.02
2	17.27	1.69	18.96
3	18.17	0.85	19.02
4	18.58	0.43	19.01
			4)76.01
			19.00

Since the method employs the use of all the observed values for the evaluation of the constants M, A, and R, these constants carry more weight than those determined by Mitscherlich's (2) method. His method of calculating the constants is as follows: He chooses any three values of x (x representing units of fertilizer) such that $x_3 - x_2 = x_2 - x_1$, and substitutes the numerical values of x and y (y representing yields) obtained experimentally into his equation and obtains three equations, from which he calculates his constants. This method of calculation is faulty and objectionable because in cases in which the number of observations is large, as in many of his experiments, different values of constants are obtained when other values of x are substituted in the equation.

Returning to the Spillman calculation, the desired yield equation for the plant crop is therefore $Y = 19.00 - 6.70 (0.503)^x$ 7

A comparison of the actual harvesting data of the plant crop with the calculated yields by means of equation 7 shows the agreement quite satisfactory. (See Table 3.)

The reader is reminded that in experiments where, due to some depressing factor, negative increases take place, this method cannot be used because negative numbers do not have logarithms.

The method of deriving the yield equation for the cycle is slightly modified. The potash applications increase by four increments of 100

TABLE 3.—*Comparison of the plant crop harvest yields with the calculated yields.*

Units of potash	Pounds of potash per acre	Actual tons per acre of pineapples	Calculated tons per acre of pineapples	Difference, tons per acre
1	100	15.65	15.63	+0.02
2	200	17.27	17.31	—0.04
3	300	18.17	18.15	+0.02
4	400	18.58	18.57	+ 0.01

pounds from 220 pounds to 520 pounds. If we take 220 pounds as the point of origin, the units of 100 pounds will be equal to 0 at 220, 1 at 320, 2 at 420, and 3 at 520, with corresponding yields of 39.20, 42.44, 45.36, and 46.88 tons per acre. (See Table 1.)

By exactly the same procedure as that used in deriving the equation for the plant crop, we get $\log R = -0.1644$ whence $R = 0.685$, and $\log A(1 - R) = 0.5503$ whence $A = 11.28$ tons, and $M = 50.45$ tons for the cycle crop. The yield equation is then

$$Y = 50.45 - 11.28 (0.685)^x \qquad 8$$

in which the origin is at (220, Y) and x is in units of 100 pounds. In Table 4 will be found a comparison between the calculated and observed yields.

TABLE 4.—*Comparison between observed and calculated yields for the cycle crop.*

Units of potash	Pounds of potash per acre	Actual tons of pineapples per acre	Calculated tons of pineapples per acre	Difference, tons per acre
0	220	39.20	39.17	+0.03
1	320	42.44	42.72	—0.28
2	420	45.36	45.16	+0.20
3	520	46.88	46.82	+0.06

It is necessary to shift our origin from (220, Y) to the natural zero point (0, Y). This is done by replacing the x in equation 8 by x — 2.20, since the 220-pound point lies 2.20 units beyond the natural zero point. Therefore, the equation changes to

$$\begin{aligned} Y &= 50.45 - 11.45 (0.685)^{x - 2.20} \\ &= 50.45 - 11.45 (0.685)^x (0.685)^{-2.20} \\ &= 50.45 - 25.93 (0.685)^x \qquad 9 \end{aligned}$$

Equations 7 and 9 are the most probable yield equations for the plant and cycle crops, respectively, as determined by the method, in which Y is the yield in tons per acre and x is the number of units of 100 pounds of potash per acre. The calculations in Tables 3 and 4 serve as tests of the reliability of the estimate.

THE ECONOMICAL LIMIT OF FERTILIZATION

We have taken as the definition of economical limit of fertilization the point of maximum returns rather than maximum return per

dollar invested or maximum return on land. In these calculations the cost of land, land preparation, weeding, and other cultural operations are considered a fixed charge which do not materially change whether the yield be 15 or 40 tons per acre. Furthermore, the questions of most economical fruit size from the cannery standpoint, of fruit quality, and of vigor of planting material taken from the mother plants are not considered. The data thus obtained are only a first approximation as to the most economical fertilization.

Since the increase in yield grows less and less as the amounts of fertilizer applied increase, there must be a point where the value of the increased fruit obtained per unit of fertilizer added is less than the cost of that fertilizer unit. Fertilization beyond this point causes decreasing profits.

We will employ the yield equation for the plant crop, equation 4 in the previous paper (1), and show how it aids in calculating the point of greatest profit. The equation follows:

$$Y = 19.10 - 6.38\ (0.538)^x \qquad 10$$

These calculations are based on the same reasoning and follow closely the methods given by Spillman and Lang (3), Spillman (4), and Verret and Kutsunai (5). If the value of 1 ton of pineapples is V dollars and x units of potash produce Y tons of pineapples per acre, then the total value of pineapples per acre is VY dollars. If 1 unit of potash costs K dollars and the amounts of nitrogen and phosphoric acid applied per acre cost L dollars, then the total cost of the fertilizer is $(L + Kx)$ dollars. Since profit arising out of a ton of fruit is equal to the value of a ton of pineapples less the cost, we have

$P = VY - (L + Kx)$ as the profit equation in which P = value of fruit less the cost of fertilization in dollars per acre. But $Y = M - AR^x$. Substituting,

$$P = V\ (M - AR^x) - (L + Kx) \qquad 11$$

Assuming that the value of a ton of pineapples is \$25.00, and that the cost of N is 12.0 cents, P_2O_5, 7.0 cents, and potash (K_2O) 6.3 cents per pound; then, 287½ pounds of nitrogen and 150 pounds phosphoric acid, or the amounts applied per acre, will cost \$45.00, and 1 unit of 100 pounds potash will cost \$6.30. Substituting these prices in equation 11 and the constants M, A, and R from the yield equation of the plant crop,

$$P = 25\left[19.10 - 6.38\ (0.538)^x\right] - (45.00 + 6.30x) \qquad 12$$

Values obtained by solving equation 12 for various values of x are given in Table 6.

TABLE 6.—*Profit in dollars per acre for each unit of potash fertilizer applied up to 8 units.*

Units of potash (K_2O) x	Pounds of potash applied per acre	Value of fruit per acre VY	Cost of fertilizer per acre L+Kx	Value of fruit less cost of fertilizer, P
0	0	$318.00	$45.00	$273.00
1	100	391.75	51.30	340.45
2	200	431.50	57.60	373.90
3	300	452.50	63.90	388.60
4	400	464.00	70.20	393.80
5	500	470.25	76.50	393.75
6	600	473.75	82.80	390.95
7	700	475.50	89.10	386.40
8	800	476.50	95.40	381.10

The results given in Table 6 are visualized in Fig. 1 in which the curve is the graph of equation 12, the values of x being abscissas and of P ordinates. With no potash fertilizer the crop shows a profit of $273.00 as indicated by the last column of Table 6. With 8 units of potash, a profit of $381.10 is shown. Profits increase up to $393.80 with 4 units of fertilizer, pass through a maximum, and then decrease.

The figures in the last column of Table 6 are not to be taken as those actually realized as net profit because several large items of expense, such as land rental, cost of preparation, planting, weeding, harvesting, etc., have been omitted from the calculations. Hence the profits are only relative insofar as these items are omitted.

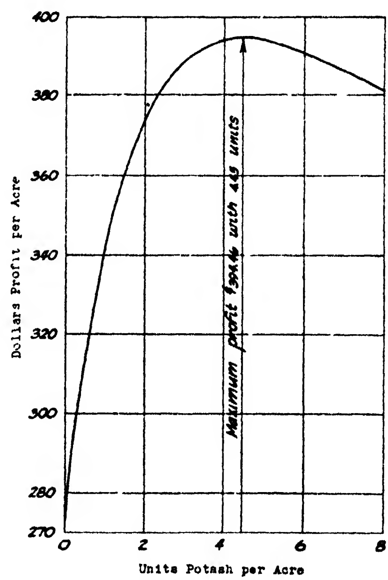

FIG. 1.—Profit at various amounts of fertilization. Profit here equals value of fruit minus fertilizer cost.

With the aid of calculus, we can determine the point of greatest returns. This is done by differentiating the profit equation 11 with respect to x, setting the resulting equation equal to zero, and after substituting the proper constants, solving for x. This is shown below:

Equation 11 is $P = V(M - AR^x) - (L + Kx)$. Differentiating with respect to x,

$$\frac{dP}{dx} = -2.303\ VA \log_{10}R.R^x - K$$

When $\frac{dP}{dx} = O, - 2.303 \text{ VA } \log_{10}R.R^x - K = O$

Then $R^x = \frac{K}{-2.303 \text{ VA } \log_{10}R}$

Taking logarithms on both sides, we have $x \log R = \log K - \log (-2.303 \text{ VA } \log_{10}R)$, whence $x = \frac{1}{\log R}\left[\log K - \log (-2.303 \text{ VA } \log_{10}R)\right]$ 13

Substituting the prices and constants of the plant crop into equation 13, we get

$$x = \frac{1}{\log (0.538)} . \log 6.30 - \frac{\log (-2.303.25.6.38.\log 0.538)}{\log 0.538} = \frac{0.799}{-0.269} + \frac{1.9948}{0.269} = -2.97 + 7.42 = 4.45$$ units or 445 pounds of potash.

Therefore, an application of 445 pounds of potash per acre brought in maximum profits; and by substitution of 4.45 for x in equation 12, the profit per acre was \$394.46.

The profit equation for the cycle crop was $P = 25\left[49.95 - 28.55 (0.654)^x\right] - (63.43 + 6.30x)$ in which the yield equation was equation 8 of the previous paper (1).

Profit was maximum and equivalent to \$1,113.11 per acre when $x = 9.12$ units, or 912 pounds per acre.

To find the yield of pineapples which would bring in maximum profits, we substitute 4.45 and 9.12 units for x in the yield equations of the plant and cycle crops, respectively, and solve for Y.

$$Y = 19.10 - 6.38 (0.538)^{4.45}$$
$$Y = 49.95 - 28.55 (0.654)^{9.12}$$

The values of Y thus obtained were 18.69 tons and 49.36 tons per acre, respectively.

ECONOMICAL LIMIT OF FERTILIZATION FOR CHANGING PRICES OF FRUIT AND FERTILIZER

The economical limit of fertilization was determined for a specific case where value of fruit and fertilizer cost were given certain definite values. With changing fruit values and fertilizer costs, new economical limits of fertilization appear. For any particular experimental area economical limits of fertilization can be calculated using various combinations of fruit and fertilizer prices over a reasonable

range of values. Such calculations have been made by substituting for V in equation 13 values of \$10, \$15, \$20, \$25, and \$30 per ton; and for K, the cost of potash fertilizer, \$4, \$6, \$8, and \$10 per 100 pounds. The values so obtained for the cycle crop are given in Table 7.

TABLE 7.—*Economical limit of fertilization for the cycle crop for the price of fruit range \$10 to \$30 per ton and potash cost \$4 to \$10 per 100 pounds.**

Value of fruit per ton	Cost of potash per 100 lbs. in dollars			
	\$4	\$6	\$8	\$10
\$10	804	708	640	588
\$15	899	803	735	683
\$20	967	871	803	751
\$25	1,019	924	856	804
\$30	1,062	967	899	846

*The values in the table are pounds of potash per acre.

The data in Table 7 show that with K_2O at 10 cents a pound and fruit valued at \$15 a ton it is economical to apply 683 pounds of potash and no more. With fertilizer at the same price and fruit valued at \$30 a ton, it is economical to apply 846 pounds potash. However, if the cost of fertilizer is only 4 cents per pound, it pays to apply 1,062 pounds of potash. These data can be expressed more clearly as a surface as shown in Fig. 2.

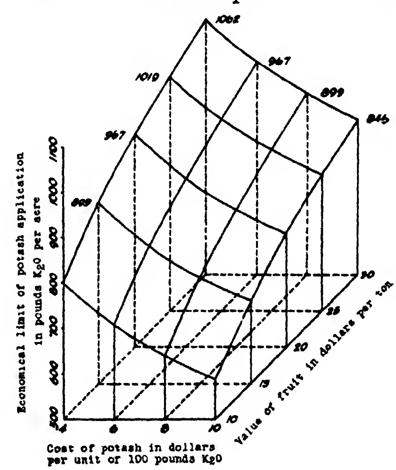

FIG. 2.—A surface showing the economical limit of potash fertilization at various costs of fertilizer and values of fruit.

In Fig. 2 cost of fertilizer per hundred pounds is plotted on the X axis, value of fruit per ton along the Y axis, and economical limit of fertilization in pounds per acre along the Z axis. A point can be selected in the XY plane to represent any given combination of fertilizer cost and fruit value. The length of the perpendicular erected at this point and touching the surface, gives the economic limit of fertilization as previously defined under those conditions.

The surface as drawn in Fig. 2 has the advantage in presenting a clear picture of how the economical limit of fertilization is affected by changes in cost of the fertilizer and the value of the fruit. The

following will be an attempt to represent graphically by a series of straight lines the same results obtained from the surface. It will be recalled that the surface is the trace of the equation $x = \frac{1}{\log R} \cdot \log K - \frac{\log(-2.303 \text{ VA} \log R)}{\log R}$ in which x was solved when K and V assumed various values. R and A are known constants and x is the number of units of fertilizer necessary to obtain maximum returns.

If we assign to V a particular value, say V_1, the equation takes the form $x = a \log K + C$, in which a and C are constants, equal to $\frac{1}{\log R}$ and $\frac{1}{\log R} \cdot \log(-2.303 \; V_1 A \log_{10} R)$, respectively. It is evident then that a straight line results when x is plotted against log K, with $\frac{1}{\log R}$ as slope and $\frac{1}{\log R} \cdot \log(-2.303 \; V_1 A \log_{10} R)$ as intercept. For instance, when V assumes the value of \$15 per ton the equation for the most economical point of fertilization for the plant crop is $x = \frac{1}{\log 0.538} \cdot \log K - \frac{\log(-2.303 \times 15 \times 6.38 \times \log 0.538)}{\log 0.538}$ or $x = -3.718 \log K + 6.592$.

This equation when x is plotted against log K gives a straight line having a negative slope of 3.718, and cutting the x axis at 6.573 units above the origin. With other values of V, straight lines having the same slopes but different intercepts are obtained. Hence, the equations for the most economical point of fertilization for the plant crop are as follows:

(1) $x = -3.718 \log K + 5.933$ when V = \$10 per ton
(2) $x = -3.718 \log K + 6.592$ when V = \$15 per ton
(3) $x = -3.718 \log K + 7.056$ when V = \$20 per ton
(4) $x = -3.718 \log K + 7.417$ when V = \$25 per ton
(5) $x = -3.718 \log K + 7.711$ when V = \$30 per ton

These equations are visualized in Fig. 3. The logarithm of cost of fertilizer per unit is plotted along the horizontal axis and the economical limit of fertilization in units of 100 pounds per acre is plotted along the vertical axis. For a known fruit value and for any value which K assumes, it is simple to find the number of units of fertilizers to apply per acre to obtain the maximum profit. For example, referring to Fig. 3, with fruit valued at \$25 per ton and fertilizer costing \$6 per unit of 100 pounds each, we find that the economical limit of application is 4.53 units, or 453 pounds of fertilizer.

The equations for the cycle crop are as follows:

$$(6)\ x = -5.423 \log K + 11.300 \text{ when } V = \$10 \text{ per ton}$$
$$(7)\ x = -5.423 \log K + 12.254 \text{ when } V = \$15 \text{ per ton}$$
$$(8)\ x = -5.423 \log K + 12.932 \text{ when } V = \$20 \text{ per ton}$$
$$(9)\ x = -5.423 \log K + 13.458 \text{ when } V = \$25 \text{ per ton}$$
$$(10)\ x = -5.423 \log K + 13.887 \text{ when } V = \$30 \text{ per ton}$$

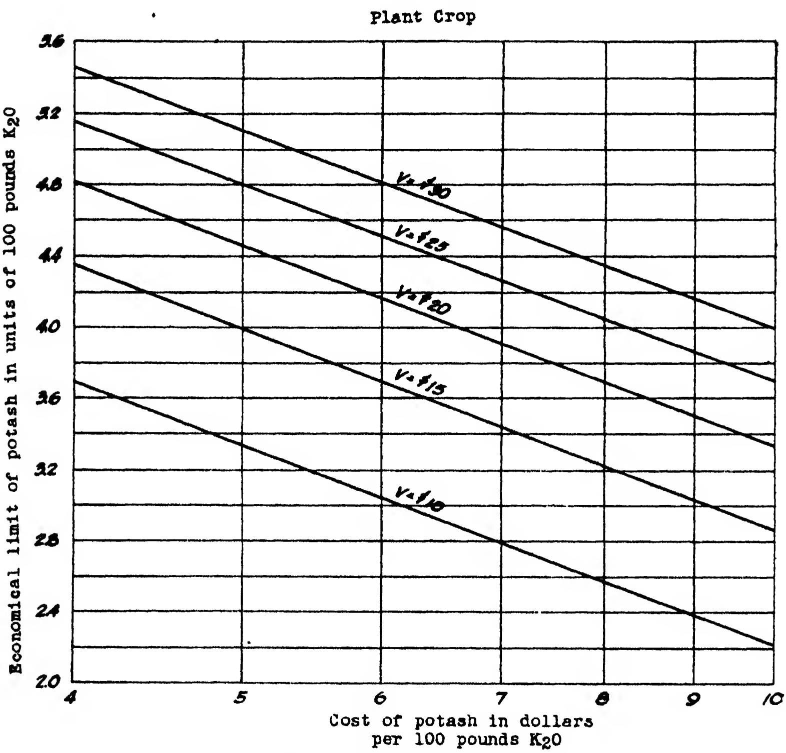

FIG. 3.—Economical limit of potash fertilization for plant crop at various costs of potash and values of fruit.

These equations are found plotted in Fig. 4. Similarly, the economical limit of fertilization may readily be found from the figure.

SUMMARY

1. A method for determining the constants in the yield equation $Y = M - AR^x$ is presented. This method, developed by Spillman, is simpler than the one presented in a previous paper (1). It is limited, however, to use only when the fertilizer treatments vary by definite arithmetic units and when the yield increases are positive. Inasmuch as fertilizer experiments are very often conducted in a

manner in which crop yields are obtained from fertilizer treatments which vary by definite increments, the authors recommend the use of this method whenever it is possible to do so.

2. By the use of the yield equations and with given values of fruit and of fertilizer cost, it is possible to calculate the point of maximum

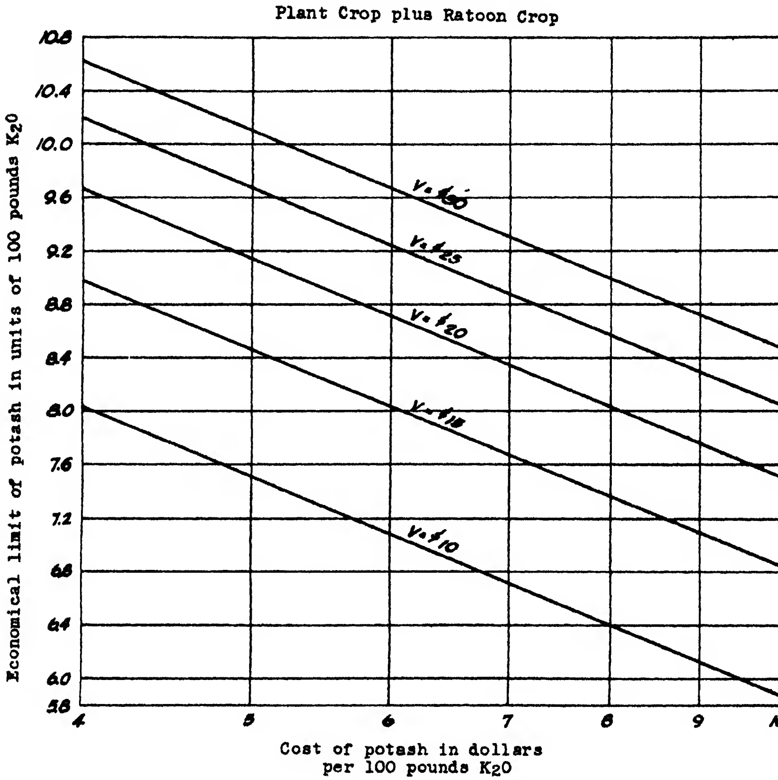

FIG. 4.—Economical limit of potash fertilization for the cycle at various costs of potash and values of fruit.

profit. In making this calculation a number of side issues were not considered, although they may be of considerable magnitude. These include, among others, residual effect of fertilizer on succeeding crops, vigor of planting material derived from the fruiting plants, and fruit quality. On these secondary factors we have so little information available that we cannot accurately evaluate their magnitude. The economic limits of fertilization as determined for any combination of fruit and fertilizer profits should therefore be considered as a first approximation only.

3. The changes in magnitude of the economical fertilization quan-

tity with changing fruit and fertilizer values have been calculated and shown graphically as a surface.

4. From the point of view of simplicity, linear relationship is shown between the limit of economical fertilization and the logarithm of the cost of fertilizer. The equations and graphs obtained enable one to obtain the same results from them as from the surface.

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REGISTRATION OF IMPROVED WHEAT VARIETIES, VII.[1]

J. ALLEN CLARK[2]

Six previous reports present the registration of 270 varieties of wheat. In 1931,[3] three varieties were registered, and the previous registrations were cited or referred to.

Varieties approved for registration this year are as follows:

Varietal Name	Registration No.
Baldrock	271
Yogo	272
Quivera	273

BALDROCK, REG. No. 271

Baldrock (C. I. No. 11538) was produced by the Michigan State College, East Lansing, Mich., from a field hybrid between Red

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 5, 1932.

[2]Senior Agronomist, Wheat Investigations, U. S. Dept. of Agriculture. Member of the 1932 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, VI. Jour. Amer. Soc. Agron., 23: 1010-1012. 1931.

Rock and some unknown variety. This hybrid was probably produced in 1916. Many awnless selections were made from it and tested from 1917 to 1922. Baldrock is one of these strains. It was increased in 1930 and 145 bushels of seed were distributed to farmers in 1931. The advantages of this variety are that it is bald winter-hardy, a good yielder, with stiff straw and satisfactory flour quality. Comparative experimental yields furnished by E. E. Down and H. M. Brown, the breeders, are given in Table 1.

TABLE 1.—*Comparative yield data of Baldrock and two other varieties of soft winter wheat grown in 1/40th-acre plats at East Lansing, Mich., 1925–31.*

Variety	Yield in bushels per acre								Percentage of Red Rock
	1925	1926	1927	1928	1929	1930	1931	Average	
Baldrock (new)...	15.9	12.5	37.9	30.3	48.4	34.8	23.7	29.1	107.4
Red Rock (stand.)	7.6	10.9	40.7	21.5	41.0	38.7	29.2	27.1	100.0
American Banner.	14.7	13.4	38.7	22.6	33.2	36.4	26.0	26.4	97.4
Berkeley Rock...	9.5	12.4	35.8	24.7	36.1	38.7	23.7	25.8	95.2

Further information on Baldrock is given in Michigan Agricultural Experiment Station Special Bulletin 223, 1932.

YOGO, REG. No. 272

Yogo (C. I. No. 8033) was produced from a cross Minturki (6155) x Beloglina-Buffum (5546) made in 1919 by J. H. Martin and K. S. Quisenberry at the Kansas Agricultural Experiment Station, Manhattan, Kans., in a cooperative winterhardiness breeding program. The parent Beloglina-Buffum (5546) was developed from a cross made in 1914 by F. R. Babcock at the Williston Substation, Williston, N. Dak., the final selection being made in 1917. The Minturki x Beloglina-Buffum cross was grown at Chico, Calif., in F_1 (1920) and at Manhattan, Kans., in F_2 (1921). The seed from the F_2 generation was sent to Moccasin, Mont., where it was grown in bulk from 1922 to 1925. Head selections made from this cross at the Judith Basin Branch Station, Moccasin, Mont., in 1923, resulted in Yogo, C. I. No. 8033. This strain was first entered in the replicated rod-row nurseries at Moccasin, Mont., and Dickinson, N. Dak., in 1925, and the plat experiments at Moccasin in 1928. The selecting and testing work at Moccasin were done by R. W. May, B. B. Bayles, and J. L. Sutherland. Application for the registration of this variety is made by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Montana Agricultural Experiment Station.

The superior characters upon which registration is based are high yield, winterhardiness, and bunt resistance. The data are presented in Table 2.

TABLE 2.—*Comparative yield, winterhardiness, and bunt data of Yogo and three other hard red winter wheats grown in plat experiments at the Judith Basin Branch Station, Moccasin, Mont., 1928-32.*

Variety	C. I. No.	Year					Average	Percentage of Karmont
		1928	1929	1930	1931	1932		
		Yield per acre						
Yogo	8033	18.6	24.3	18.6	2.9	35.3	19.9	125.9
Newturk	6935	3.6	26.0	20.6	0.0	31.1	16.3	103.2
Karmont	6700	1.6	23.0	20.4	0.0	34.2	15.8	100.0
Turkey	1558	3.1	21.9	20.6	0.0	31.8	15.5	98.1
		Spring Survival						
Yogo	8033	75	100	100	16	100	78	123.8
Karmont	6700	15	100	100	0	100	63	100.0
Turkey	1558	18	95	100	0	100	63	100.0
N wturk	6935	10	98	100	0	100	62	98.4
		Bunt Resistance						
Yogo	8033	2	3	9	1	3	4	11.4
Newturk	6935	48	1	53	0	50	30	85.7
Karmont	6700	42	5	62	0	67	35	100.0
Turkey	1558	24	2	68	33	79	41	117.1

Further information on the development of Yogo is given under Minturki x Beloglina-Buffum, C. I. No. 8033, in U. S. Dept. of Agriculture Technical Bulletin 136, 1929.

QUIVERA, REG. No. 273

Quivera (Kans. No. 2628, C. I. No. 8886) was produced from a hybrid between Prelude (female) and Kanred (male). The cross was made by V. H. Florell in 1920 at the U. S. Plant Introduction Garden, Chico, Calif. Seed from the F_1 plants was sent to the Kansas Agricultural Experiment Station, Manhattan, Kans., for fall seeding in 1921. Selections were made at Manhattan by J. H. Parker until 1924. The selection from which Quivera resulted was grown in an 8-foot row in 1925, in the replicated rod-row nursery in 1926–27, and in the plat experiments since the fall of 1928. Application for the registration of this variety is made by the Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Quivera is bearded and has white pubescent glumes and hard red kernels of good quality. Its principal advantage is that it is from 6 to 7 days earlier than Kanred. The comparative data upon which registration is based are shown in Table 3.

TABLE 3.—*Comparative data of Quivera and other varieties of hard red winter wheat grown at the Kansas Agricultural Experiment Station, Manhattan, Kans., 1927–32.*

Variety	Year 1927	1928	1929	1930	1931	1932	Average	Percentage of Kanred
			Nursery Experimetns					
Yield:								
Quivera (new)	49.0	59.0	27.4	56.7	47.9	58.2	49.7	141.2
Kanred (standard)	21.8	49.2	16.5	32.7	34.2	56.6	35.2	100.0
Date headed (May):								
Quivera	20	20	22	12	18	15	18	—
Kanred	27	24	29	22	27	21	25	—
			Plat Experiments					
Yield:								
Quivera (new)	—	—	22.1	28.5	45.5	54.3	37.6	106.2
Tenmarq	—	—	24.3	40.4	47.4	53.4	41.4	116.9
Blackhull	—	—	18.1	32.8	47.5	49.2	36.9	104.2
Kanred (standard)	—	—	14.8	33.6	47.1	46.0	35.4	100.0

NOTES

THE RELATIVE COST OF PLANT FOOD ELEMENTS IN FERTILIZER MATERIALS

The statement is frequently heard that nitrogen is the most costly plant food element. This statement was unquestionably true a number of years ago; but there has been, in recent years, a much greater decrease in the prices of nitrogen carriers than in the prices of carriers of other plant food elements.

An inspection of fall fertilizer price lists for the states of Ohio, Indiana, and Michigan leads to the following average prices per ton for this territory: Muriate of potash, 50%, at $49.50; sulfate of ammonia, 20.8%, at $29.50; 20% superphosphate at $26.40; and 45% superphosphate at $51.75. The cost per unit of plant nutrients based on these prices is $0.99 for potash, $1.42 for nitrogen, and $1.32 and $1.15 for phosphoric acid in the 20% and 45% superphosphate, respectively. According to these figures, it might again be said that nitrogen is the most costly of the plant food elements. In arriving at this conclusion, however, it will be noted that the price of elemental nitrogen has been considered, while the costs of potash and phosphoric acid have been figured in terms of K_2O and P_2O_5, respectively. This method of calculation is evidently erroneous, since plants do not feed on elemental N any more than they do on elemental P and K.

To place the matter on a comparative basis, the cost of each plant nutrient should be calculated on the elemental basis. Following this method of calculation, we find that while nitrogen costs $1.42 per unit, phosphorus costs $3.02 per unit in 20% superphosphate and $2.63 per unit in 45% superphosphate, and that the cost of potassium is $1.19 per unit. It is evident from these figures that phosphorus

and not nitrogen is the most costly plant food element, on the basis of the prices quoted.

The wholesale seaboard quotations on August 29, 1932, for several fertilizer materials were as follows: Sulfate of ammonia in 200 pound bags, $22.00 per ton; muriate of potash in bags, $35.29 per ton; cyanamid in bags, $0.975 per unit. Superphosphate was quoted in the 16% grade only at $8.00 per ton in bulk. Adding $1.75, which according to the quotations for other materials appeared to be about the average charge for bagging, we get a cost of $9.75 per ton. According to these prices, unit costs of nitrogen were $1.06 in sulfate of ammonia and $0.975 in cyanamid, while phosphorus and potassium cost $1.39 and $.85 per unit, respectively.

From these data it is seen that phosphorus is again the most costly plant food element, followed in order by nitrogen and potassium.

Evidently many of us have been in error in our method of calculating the relative costs of the various plant food elements. We have doubtless fallen into this mistake through the practice of expressing the nutrient content of mixed fertilizers in terms of nitrogen, phosphoric acid, and potash. In order to present the relative costs of the plant nutrients on a scientifically correct basis, we should base our calculations on the elements themselves, even though this may lead to some temporary confusion in the minds of farmers and other purchasers of fertilizers.—C. E MILLAR.

THE USE OF KAINITE FOR THE CONTROL OF POISON IVY

The herbicides conventionally used for the destruction of poison ivy are commercial sulfuric acid which is poured on the crown of the plant at stated intervals until the plant dies; or the plant may be killed by saturating the soil adjacent to the crown with a strong solution of caustic soda, or of salt. Poison ivy can also be killed by spraying the foliage. Stone[1] successfully used 2.5% solutions of either arsenate or arsenite of soda applied at a rate equivalent to 1,600 gallons per acre. Grant and Hansen[2] state that the plant is readily killed by a 37.5% solution of common salt. Kerosene is used, and Fiske[3] mentions waste oil from garages.

Sulfuric acid, caustic soda, and salt, the latter to a less extent, are destructive to plant life and for a considerable time after they have been used the soil remains barren. Arsenate and arsenite of soda are powerful herbicides and very poisonous to animal life. Kerosene and waste oil are inflammable and there is always danger from fire following their use. Furthermore, they can not be applied to poison ivy growing upon or against arboreal plants because they will penetrate the tissues of the stem and branches and cause disturbances in metabolism.

[1]STONE, G. E. Effects of chemicals on vegetation. Mass. Agr. Exp. Sta. Rpt., 21: 1–62. 1909.

[2]GRANT, C. V., and HANSEN, A. A. Poison ivy and poison sumac and their eradication. U. S. D. A. Farmers' Bul. 1166. 1920.

[3]FISKE, JESSIE G. Poison ivy. N. J. Agr. Exp. Sta. Circ. 206. 1927.

Poison ivy grows along fence rows, old stone walls, and in and about trees, and the proposed methods of control are for the most part inapplicable for one reason or another. An herbicide that is non-toxic to soil, that will not injure arboreal plants growing amidst poison ivy, and that can be broadcasted by hand is much to be desired. Experiments made by the writer during the last few years indicate that Kainite meets the desiderata required.

Kainite is a potash fertilizer containing 14% K_2O and having the following average composition:[4]

Potassium chloride	22.1%
Magnesium sulfate	36.4%
Sodium chloride	23.6%
Calcium sulfate	1.6%
Insoluble material	0.6%
Water	16.1%

The potash fertilizer sold under the name of Kainite owes its name to the fact that the potash is present in the form of the mineral kainite, a double salt of the composition $KCl.MgSO_4.3H_2O$. However, the name has not always been applied in this strict sense. According to a number of older texts, the potash present in the crude salt sold under the name of Kainite is said to be a mineral of the following composition: $K_2SO_4.MgSO_4.MgCl_2.6H_2O$, but this is apparently simply schoenite (picromerite) $MgSO_4.K_2SO_4.6H_2O$ admixed with magnesium chloride. According to Wheeler,[5] the composition of the fertilizer Kainite of this type is as follows:

Potassium sulfate	21.3
Potassium chloride	2.0
Magnesium sulfate	14.5
Magnesium chloride	12.4
Sodium chloride	34.6
Calcium sulfate	1.7
Insoluble material	0.8
Water	12.7

The crude potash fertilizer of the above composition is quite hygroscopic and cakes so readily that peat is usually added to it to keep it in condition. Possibly owing to a misconception, the crude potash fertilizer derived from the mineral kainite is frequently also supplied with peat added to it to keep it in condition, but it is doubtful if in our climate it is necessary to do so.

The Kainite used in the present experiments on poison ivy has been of the type represented by the first analysis. The fertilizer was ground to various degrees of fineness with and without the addition of peat and the mechanical analysis of the samples employed is given in Table 1.

All the samples of Kainite used have been effective in killing poison ivy, but the finely ground samples distribute better and adhere to the foliage better than the coarser. Kainite of the type represented by

[4]S. D. Gray, N. V. Potash Export My., supplied the analysis given.

[5]WHEELER, H. J. Manures and Fertilizers. 1913.

sample C is convenient to apply, adheres to moist foliage well, and can be easily brought back into condition after standing over winter in a jute bag. In fact, it was more easily freed from lumps than finely ground Kainite containing peat (sample B).

TABLE 1.—*Mechanical analysis of Kainite used for the eradication of poison ivy.*

Mesh per square inch	Per cent passing through sieves		
	With peat		Without peat
	A, coarsely ground	B, finely ground	C, finely ground
35	20.84	97.98	55.50
48	13.82	94.07	39.30
65	9.82	90.46	28.60
100	5.41	80.34	16.20

To kill poison ivy the Kainite is broadcast on the plants, care being taken to cover all the leaves thoroughly when the foliage is wet by dew or rain. In gardens and around dwellings when water is available, the foliage can be wetted and the salt applied at any time to suit personal convenience. Ordinarily, poison ivy sprouts again after treatment, so that two or more applications may be required. The amount of Kainite required will vary with the size and density of the plants. An allowance of 0.1 pound per square foot, however, will usually be found more than sufficient for the first application.—O. BUTLER, *New Hampshire Agricultural Experiment Station, Durham, N. H.*

AN ATTEMPT TO CONTROL THE REACTION OF A SOIL

A note recording experiments conducted by the Agronomy Department of the University of Delaware in an attempt to control the hydrogen-ion concentration of Sassafras silt loam under field conditions, might be of value to those working along this line.

The experiments were begun in 1925. At first the object was to establish a fairly wide range in the reaction of this soil. To bring about this change, lime and sulfur were applied at different rates. Some areas were left untreated as checks. It was not until 1928, after lime (the first application being hydroxide and the others ground limestone) and sulfur had been applied three times that the desired range in reaction was established.

After the range had been established, the problem was to maintain it as nearly as possible under crop conditions and to determine the amount of variation in the reaction of the soil, especially during the summer months. In order to do this, it was decided in 1929 to divide the area into 121 plats. Most of them were 12 by 18 feet, but a few were 12 by 36 feet. Fifty-five of them had been treated with sulfur, 55 with lime, and 11 had not been treated. Alfalfa, bluegrass, timothy and clover, beets, snap beans, tomatoes, and cabbage were grown on the plats.

Between 1929 and 1931, inclusive, the pH of the soil from every plat was determined twice each summer—about the last of June and

again the middle of August. A soil sample was secured by taking 10 borings from a plat to a depth of 6 2/3 inches with a soil auger. The borings were thoroughly mixed. The reaction was determined potentiometrically, using a quinhydrone electrode.

It was not necessary to apply lime to the limed plats after 1928, but such was not the case with the sulfur plats. The first pH determinations in 1929 indicated that the acidity of the sulfur plats was disappearing, and it was concluded that if the acidity were to be maintained yearly applications of sulfur would be necessary. When this was discovered sulfur was applied in the summer, but in 1930 and 1931 it was applied in the spring, it being supposed that spring applications would produce less fluctuation in acidity during the growing season. The sulfur was cultivated into the soil, except in the case of the sod crops where surface applications were made.

Since sulfur had to be applied from time to time, there was considerable variation in the pH of the soil from the same plat. During the growing months the most uniform pH of the sulfur plats was secured in 1930 and 1931 when the sulfur was applied in the spring. But even in those two years the fluctuation in the reaction of identical plats in the same summer was great. In five cases it was more than a pH unit, one being 1.37. There were several cases in a summer with variations from 0.6 to 0.8 pH unit, and fluctuations from 0.4 to 0.5 pH unit occurred frequently.

Over the 3-year period the variation in reaction of a limed plat was not much greater than was sometimes found during one summer. In eight instances the reaction of a limed plat during the growing season fluctuated 0.5 pH unit or more, one being 0.75. There were a number of instances in a summer where the variation in the pH of a plat was 0.3 to 0.4 unit.

The reaction of the check plats also fluctuated. Over the 3-year period the variation in the pH of a check plat was not much greater than that often found for one summer. In one case during a summer the fluctuation in the reaction of the soil was 1.05 pH units. Three cases were found where in the same summer the variation ranged from 0.7 to 0.95 pH unit, and differences from 0.2 to 0.4 pH unit were common.

In 1931, samples of soil were taken at different depths. In the case of the cultivated crops the samples were taken from the 1- to 7-inch depth and from the 7- to 18-inch depth, while in the case of the sod crops the samples were taken from the 1- to 3½-inch, 3½- to 7-inch, and 7- to 18-inch depths. The pH determinations of these samples showed that the reaction of the check plats was about the same at different depths, while the plats on which lime had been applied were less alkaline at the deeper depths and the plats on which sulfur had been applied were less acid at the deeper depths. Where sulfur was applied there was in some cases a difference of about 1.5 pH units in the reaction of the soil from the 1- to 3½- inch depth and the 3½- to 7-inch depth of the same plat.

An effort was made to see if there were a relation between the season and the direction of change in reaction of the soil during the summer months. The results are given in Table 1.

TABLE 1.—*Change in pH of the soil during the same summer.*

Number of plats classified and treated	1929			1930			1931		
	pH decreased	pH increased	No change in pH	pH decreased	pH increased	No change in pH	pH decreased	pH increased	No change in pH
11 checks..	3	7	1	10	1	0	3	8	0
55 plats on which lime was applied	13	39	3	50	5	0	9	44	2

The table suggests that there are seasonal factors which cause the reaction of this soil to change in one direction one summer while the next summer it may change in the opposite direction. No figures on the rainfall are available, but it is suspected that the amount of rain has something to do with the change.

These experiments show that by the methods and treatments used, it is very difficult to control to any great degree of exactness the reaction of this soil under field conditions.—HENRY C. HARRIS, *University of Delaware, Newark, Del.*

BOOK REVIEWS

SOILS: THEIR ORIGIN, CONSTITUTION, AND CLASSIFICATION. AN INTRODUCTION TO PEDOLOGY

By Gilbert Wooding Robinson. New York: D. VanNostrand Co., 390 pages, illus. 1932.

In the words of the author, the aim in this work has been to give a general view of pedology within the compass of a book of moderate size It is recognized by the author, however, that to accomplish this only a very broad treatment is possible of a subject which is increasing in scope so rapidly. An examination of the book indicates that the author has succeeded very well in accomplishing his purpose.

The book deals with the origin, constitution, and properties of soils, including such subjects as soil-forming processes, the clay complex and base exchange, organic matter, and water relations The main soil groups of the world are then described from the standpoint of genetic relations. Something is said also of classification and geography of soils.

A small portion of the book is given over to the subjects of soil survey, analysis, and the relations of soils to plants and agriculture. An appendix of some 12 pages deals with methods of analysis. General rather than detailed procedure is given in the latter.

References to literature are general and suggestive rather than exhaustive. The book, dealing as it does with the subject from the modern viewpoint, will give the student of the soil itself a broad comprehensive view of the fundamentals and of the newer aspects of soil science. (R. C. C.)

UNKRÄUTER IN ACKERBAU DER NEUZEIT (WEEDS IN MODERN FARMING)

By Emil Korsmo. Berlin: Julius Springer. 580 pages, illus. Ed. 2. 1930.

This book, revised by the auther and translated into the German by Dr. H. W. Wollenweber, first appeared in 1925 in the Norwegian language under the title "Ugress i nutidens jordbruk (Weeds in farming at present)."

In the first chapter weeds are classified according to length of life and their usual places of growth are given. Considerable data on the harm that weeds do, means of spread, and number of seeds of different weeds found in measured areas of cultivated land are given in the next three chapters.

In chapter five, which makes up about two-thirds of the entire volume, 209 weeds, arranged according to length of life and methods of spread, are described. Forty-four of this number were not included in the first edition. They are weeds that are more harmful in Germany and other countries than on the Scandinavian Peninsula. Excellent photographs or drawings accompany practically every description. The illustrations include in the majority of instances besides the well-developed plant, the seedling, floral parts, and seeds. A table is included giving the chemical composition of the tops and underground parts of a considerable number of weeds. Unfortunately, the stage of development of the plants at the time the samples were taken for analysis is not given.

Methods of avoiding weed infestation and of eradication after stands have become established are given in chapter six. Eradication by tillage and by the use of chemicals are discussed in detail. The results of experiments in Norway in increased yields due to weed eradication are given and discussed in the seventh chapter. The ninth chapter contains a summary and an extensive list of publications on weeds.

The author states that the material included and the arrangement are such that the book should be of value to farmers as a reference and as a guide to the study of weeds in schools. A study of the contents of the volume indicates that it can well serve these purposes.

Practically all of the worst weeds in the United States came originally from Europe. If there are abroad still other weeds equalling those already here in ability to spread and persist, they may be expected to appear in America sooner or later. This volume offers to farmers and to scientific workers in America the opportunity to know the weed pests of Europe and methods of eradication that have proved effective there. This should lead to the prompt identification and destruction of any new weed immigrants before they become well established in this country. (A. C. A.)

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh: Oliver & Boyd. XIII + 307 pages, illus. Ed. 4. 1932. 15s.

In this fourth edition of his well-known and valuable work, the author has not only increased the size of the volume by 24 pages, compared with the third edition, but has made many changes in the text either by the addition of new sections, by the substitution of new material for other that has been omitted, or by revision and amplification of the text. However, the general appearance of the fourth edition resembles the third in the fact that the numbering of the sections (except for additional sections), tables, and examples have been unaltered so that references to them remain valid regardless of the edition.

Three new sections have been added, *viz.*, 21.1, The Combination of Probabilities from Tests of Significance; 26.1, Comparison of Regression Coefficients; and, 49.1, The Analysis of Covariance. Each of these subjects is of great practical value, respectively, for (1) combining results of a number of trials, (2) for comparing relative changes in two sets of data when the number of observations is not the same, and (3) for assisting in the planning of field tests as well as for getting the most out of the data.

The most important substitution is cumulant notation for moment notation which has necessitated very many changes in formulae throughout the book. Discussion of available tables for testing significance (Section 5) has been omitted and in its place has been substituted a historical note on the principal contributors to the development of the statistical reasoning particularly as regards the theory and distributions upon which the present work is founded. To the reviewer it seems unfortunate that the account of these tables was not retained and the historical note added as an additional section. There are two reasons for this view. First, research workers unfamiliar with biometrical and statistical literature might have been led to refer to the original publications and the texts accompanying them and thus be enabled to study more thoroughly the several distributions and the reasoning underlying the development of the tables. Second, the original tables, being in a different form than those in this book, might aid in a better understanding of the distributions which they represent.

Revisions in the text have clarified a number of statements which in the earlier editions seemed inconsistent. Also, additional explanatory matter will aid workers in a better comprehension of the value of statistical methods as applied to research data.

In discussing Dr. Fisher's book, regardless of editions, with other workers who have a good working knowledge of ordinary statistical and biometrical methods, there is agreement that the author has produced an excellent text especially as regards distributions suitable for use with small samples. However, all agree that it is somewhat too technical for many non-methematical research workers, particularly those who attempt for the first time to use these methods of analysis in the interpretation of their data. What is needed in ad-

dition is an elementary work dealing with these same statistics, together with numerical examples in which every step in the computation is shown with explanations in the text giving the reason for each step. Such a work should have a wealth of material illustrating the application of these types of analysis to various portions of the biological field. It is hoped that Dr. Fisher, either alone or in collaboration with others, will see fit to produce such a text. Such an elementary treatise would greatly assist many investigators in understanding thoroughly the present work who now do not see the necessity for such analysis owing to the mistaken notion that this type of mathematics is beyond their comprehension. (F. Z. H.)

PRACTICAL METHODS IN TEACHING VOCATIONAL AGRICULTURE

By H. E. Lattig. New York: McGraw-Hill Book Co., Inc. XII+360 pages, illus. $2.50.

This book is written by a man of practical experience who has very successfully applied many of the theories of sound educational principles by clever methods of problem presentation and other aids of classroom technic. The author stresses the importance of projects as a teaching device and presents several helpful methods of articulating the project activities with those of the classroom.

Chapters include Selection of Projects, Building the Course of Study, The Lesson Plan, Putting Over the Lesson, Project Plans, Project Records and Accounts, Project Problems, Project Supervision, Farm Shop Work and Farm Mechanics, Judging and Grading Farm Products, The Evening School, The Future Farmer, Publicity, Exhibits, and Community Work, and reference material.

Although the viewpoint of the entire book is that of the teacher, an analysis of many of the problems presented should aid students and research workers in the field of agronomy, as well as in other fields of agriculture, to a broader understanding of the needs of teachers of agriculture as well as those engaged in agriculture as a livelihood. (O. M. W.)

FELLOWS ELECT

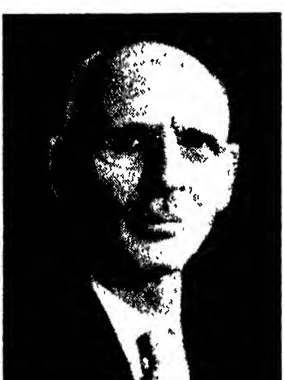
ARTHUR BISHOP BEAUMONT

Arthur Bishop Beaumont, Massachusetts State College, Amherst, Massachusetts. Born at Waco, Texas, January 21, 1887. B.S., Kentucky State University, 1908; Ph.D., Cornell University, 1918. Instructor in high school, North Bend, Oregon, 1909–10; teacher, Oregon Normal School, Monmouth, Oregon, 1911–12; graduate assistant, soil technology, Cornell University 1913–17; associate professor of agronomy, Massachusetts State College 1917–19; professor and head of the department of agronomy 1919—. Member A.A.A.S., American Society of Agronomy. Special interests include soil colloids and fertilizers.

Dr. Beaumont has served on the executive and various other committees of the Society and has participated in the programs of the annual meetings, and has made important contributions to agronomic knowledge.

ANDREW BOSS

Andrew Boss, University of Minnesota, Minnesota Agricultural College and Experiment Station, St. Paul, Minnesota. Born near Lake City, Wabasha County, Minnesota, June 3, 1867. Graduate of School of Agriculture, University of Minnesota, 1891. D.Sc. Kansas State College, 1927. Assistant agriculturist Minnesota Agricultural College, 1894–02; associate professor of agriculture, 1902–05 ; professor of agriculture and animal husbandry, 1905–10; professor of agronomy and farm management, 1910–14; professor and chief of the division of agronomy and farm management, 1914–17; professor and chief of the division of agronomy and vice-director of the experiment station, 1917–28; and professor of agriculture and farm management and vice-director of the experiment station, 1928—. Member A.A.A.S., American Society of Agronomy, American Farm Economics Association. Special interests include farm management, rural economics, and land utilization. Author of *Farm Management*.



Dr. Boss has long been a member of the Society, has served on special committees, and through his counsel and encouragement has aided in promoting the advancement of agronomic science.

MARION JACOB FUNCHESS

MARION JACOB FUNCHESS, Alabama Polytechnic Institute, Auburn, Alabama. Born at Orangeburg, South Carolina, April 9, 1884. B.S. Clemson Agricultural College, 1908; M.S. University of Wisconsin, 1911. Assistant professor of agronomy, Alabama Polytechnic Institute, 1909–12; associate professor, 1912–15; professor of agronomy, 1915–24; professor of agronomy and dean of the college of agriculture and director of the agricultural experiment station, 1924—. Member American Society of Agronomy and A.A.A.S. Special interests, soil fertility, decomposition of organic toxins in soils, crop rotations, and the low fertility of acid soils.

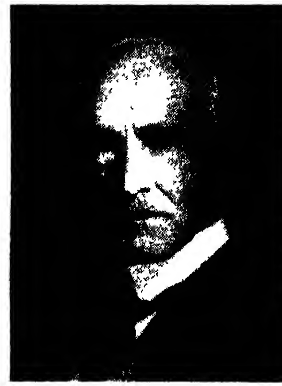
In addition to serving the Society as its president, Dean Funchess has served on the executive and various other special and standing committees, has participated frequently in the programs at the annual meetings, and has made important contributions to the sciences of soils and crop production.

SAMUEL CECIL SALMON

SAMUEL CECIL SALMON, United States Department of Agriculture, Washington, D. C. Born at Emery, South Dakota, July 25, 1885. B.S., South Dakota State College, 1907; M.S., Kansas State College, 1923; Ph.D., University of Minnesota, 1932. Special agent, U. S. Department of Agriculture, 1908–11; plant physiologist, U. S. Department of Agiculture, 1911–13; professor of farm crops, Kansas State College, 1913–31; principal agronomist, Division of Cereal Crops and Diseases, United States Department of Agriculture, 1931—. Member A.A.A.S., American Society of Agronomy, American Society of Plant Physiologists. Special interests, crop production and improvement, plant physiology, crop ecology, and the resistance of crop plants to low temperature.

Dr. Salmon has served on many standing and special committees of the Society, has made valuable contributions to the programs of the Society, and through his council and research has contributed much to the advancement of agronomy.

FRANK THOMAS SHUTT



FRANK THOMAS SHUTT, Experimental Farm, Ottawa, Ontario, Canada. Born in London, England, September 15, 1859. B.A., University of Toronto, 1885; M.A., University of Toronto, 1886; D.Sc., University of Toronto, 1914. Fellow in Chemistry, University of Toronto, 1885–87; Dominion chemist and assistant director Dominion experimental farm, 1887—. Member American Society of Agronomy, A.A.A.S., Chemical Society of England, American Chemical Society, Royal Society of Canada, London Chemical Society, and Fellow Institute of Chemistry of Great Britain. Special interests, soil fertility, conservation of soil moisture, the composition of cereals and sugar beets, and agricultural meteorology.

Dr. Shutt has been one of the leaders in his field of work for many years and through his research, writing, and lectures has made numerous valuable contributions to the field of soil science.

MINUTES OF THE TWENTY-FIFTH ANNUAL MEETING OF THE SOCIETY

The meetings of the Crops and Soils Sections of the Society were called to order at 9:00 a.m. on Thursday, November 17, at the Willard Hotel, Washington, D. C. A general session was held on Thursday afternoon at which time the twenty-fifth anniversary program was given. The annual dinner was given on Thursday evening. Sessions of the two Sections of the Society were held on Friday, November 18. About 275 members and visitors were in attendance at the various sessions. The following special committee was appointed: Auditing—F. D. Keim and H. G. M. Jacobson.

COMMITTEE REPORTS

TERMINOLOGY

The report of the Committee on Terminology was read by the Secretary and upon motion was accepted. The report was as follows:

The only matter presented to the committee for consideration during the year has been an appeal from its decision and recommendation of a year ago (Jour. Amer. Soc. Agron., 23:1020–1021, 1931), regarding the terminology of fertilizer elements. Last year, it will be recalled, your committee reported on a request, presented before the Society two years ago, that the terms nitrogen, phosphoric acid, and potash be approved for use in the literature of soils and fertilizers. After very full consideration the committee decided and recommended in favor of the names of the three elements involved, namely, nitrogen, phosphorus, and potassium, rather than in favor of the names of one element and two compounds. This decision was based primarily on the observable and encouraging trend toward greater precision and accuracy in the nomenclature of science, industry, and commerce.

Under date of February 29, 1932, the original proponent appealed from the conclusions and recommendation of the Committee and asked that the case be reopened. The communication was referred to the members of the Committee on March 15, 1932. Each member has gone on record in writing as being in favor of upholding the decision and recommendation of a year ago.

Respectfully submitted,

CHARLES F. SHAW JAMES A. BIZZELL
CHARLES A. SHULL CARLETON R. BALL, *Chairman.*

STANDARDIZATION OF FIELD EXPERIMENTS

The report of the Committee on Standardization of Field Experiments was presented by R. J. Garber, in the absence of the chairman. The report was accepted as follows:

The work of revising the Society's standards for the conduct of field and lysimeter experiments is in progress. Since this has not been completed, a continuation of the committee is requested. That considerable interest exists concerning the conduct and statistical analysis of agronomic experiments is evidenced by the large number of papers which have appeared on this subject during the past year. A list of 41 new citations is appended for inclusion in the bibliography. This list, together with the citations in previous committee reports published in the JOURNAL in January, 1924, December, 1924, December, 1926, and December, 1931, constitute the complete bibliography. The committee will appreciate having its attention called to any important omissions.

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Respectfully submitted,

R. J. GARBER
C. A. MOOERS
S. C. SALMON
L. J. STADLER
H. M. STEECE
J. W. WHITE
T. A. KIESSELBACH, *Chairman.*

VARIETAL STANDARDIZATION AND REGISTRATION

M. A. McCall presented the report of the Committee on Varietal Standardization and Registration which, upon motion, was adopted as follows:

During the year, the committee considered the matter of registering sweet corn and field pea varieties. The vote was against registration of these crops at this time.

During the year three improved varieties of wheat were registered, as follows: Baldrock, a soft red winter variety developed by the Michigan Agricultural Experiment Station; Yogo, a very cold-resistant hard red winter variety developed in cooperative experiments by the Montana Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Quivera, an early hard red winter variety adapted to Southern Great Plains conditions, developed in cooperative experiments by the Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases. A description of these varieties is presented on pages 975 to 978 of this number of the JOURNAL.

Respectfully submitted,

H. K. HAYES
E. F. GAINES
D. F. JONES
J. H. PARKER
F. D. RICHEY
T. R. STANTON
J. ALLEN CLARK
H. B. BROWN
M. A. McCALL, *Chairman*

EDUCATION IN AGRONOMY

R. I. Throckmorton, chairman, presented the report of the Committee on Education in Agronomy which, upon motion, was accepted as follows:

The commiteee on Education in Agronomy made a study during the summer of 1932 of the number of part-time and of full-time positions that have been created and the number of part-time and full-time positions that have been discontinued for each of the three fiscal years 1930–31; 1931-32, and 1932–33. Information was secured concerning the number of men on leave at full pay, part pay, and no pay for the same years. A study was also made of the number of men who received advanced degrees in 1932 and the number of these men who have received appointments.

The study was made by means of questionnaires submitted to the Land Grant Universities and Colleges of the United States. Forty-six institutions responded. A summary of that portion of the questionnaire relative to new positions created and positions discontinued shows that during 1930–31, 20 full-time and 7 part-time positions were created and that 2 full-time and 1 part-time positions were discontinued. Nine times as many total positions were created during that period as were discontinued. Fifteen of the 20 full-time positions created during the year were at three institutions, and the 7 part-time positions were distributed among five institutions.

During 1931–32, 5 full-time and 6 part-time positions were created and 11 full-time and 11 part-time positions were discontinued. Twice as many positions were discontinued as were created. The 11 positions created were distributed among eight institutions and the 22 positions discontinued were distributed among 14 institutions. By August of the current fiscal year, 1 full-time position had been created, and 18 full-time and 16 part-time positions, or a total of 34, had been discontinued. The positions discontinued were distributed among 16 institutions, but 2 institutions accounted for 14 of the 34 positions that were discontinued. During the 3-year period, 26 full-time and 13 part-time positions, or a total of 39, were created, and 31 full-time and 28 part-time positions, or a total of 59, were discontinued, as shown in Table 1.

TABLE 1.—*Positions created and discontinued in agronomy during the fiscal years 1930–31, 1931–32, and 1932–33.*

	Number of positions			
	1930–31	1931–32	1932–33	Total
	Positions Created			
Full time	20	5	1	26
Part time	7	6	0	13
Total	27	11	1	39
	Positions Discontinued			
Full time	2	11	18	31
Part time	1	11	16	28
Total	3	22	34	59

It is evident that there has been a decided reduction in the number of new positions created in agronomy during the last 2 years as compared with the first year of the period and that there has been a decided increase in the number of positions discontinued.

That portion of the study relative to the number of men who have been on leave shows a distinct tendency for a smaller number of men to be granted leave. During the fiscal year of 1930–31, 18 men were on leave with 2 on full pay, 15 on part pay, and 1 on no pay. A year later, or during 1931–32, a total of 15 men were on leave. None of these was on full pay, nine were on part pay, and six received no remuneration. During the present fiscal year, nine men have been granted leave of absence. One of these is on full pay for a period of six months, seven are on part pay, and one receives no remuneration. (See Table 2.)

TABLE 2.—*Number of men in agronomy on leave for each of the fiscal years 1930–31, 1931–32, and 1932–33.*

Status	Number of men on leave		
	1930–31	1931–32	1932–33
Full pay	2	0	1
Part pay	15	9	7
No pay	1	6	1
Total	18	15	9

That portion of the study relative to men who have been granted advanced degrees was undertaken to obtain information on the extent to which such men have received appointments. This portion of the study includes only those who have received such degrees in 1932. (See Table 3.)

TABLE 3.—*Number of men who have received advanced degrees in agronomy in 1932 and the number who have received appointments.*

Degree	Number receiving the degree	Number who have received appointments
Master of science ...	94	67
Doctor of philosophy.	17	13

Of the 94 men who were granted master's degrees, 67 had received appointments in August of this year. Part of these appointments were temporary while others were not in the field of agronomy. This means that 28.7% of these men had not received appointments in August. Thirteen of the 17 men who received their doctorate had been appointed to positions in August. Many of these returned to former positions. Approximately 23.5% of the men who had been granted their doctorate had not received appointments in August.

The smaller number of positions in the field of agronomy may mean that more graduates will fail to locate satisfactory positions and consequently will continue their studies, thus increasing the number of graduate students. However, this situation may be over-balanced by the smaller number of part-time positions which means that fewer men will be appointed to positions which offer them some remuneration while doing graduate work, by the decline in the number of men granted leave of absence, and by failure of approximately one-fourth of the men who received advanced degrees in 1932 to receive appointments.

Because of the decline in the number of positions in agronomy and the difficulties encountered by those who have recently received advanced degrees in locating satisfactory positions, it seems that only the most promising of our graduates should be encouraged to continue their studies if they are seeking more advanced degrees in order to secure employment in the agricultural experiment stations and colleges.

Respectfully submitted,

H. O. BUCKMAN   D. D. HILL
E. R. HENSON   R. I. THROCKMORTON, *Chairman.*

FERTILIZERS

A. B. Beaumont, chairman, presented the report of the Committee on Fertilizers which, upon motion, was accepted as follows:

The major contribution of this committee this year is that of having brought to a successful conclusion the study of the literature on the effect of fertilizers on crop quality. The report has been published in an attractive form by the National Fertilizer Association under the title "The Influence of Fertilizers on Crop Quality" by Burt L. Hartwell; comprising Section Two of the Proceedings of the Eighth Annual Convention of the National Fertilizer Association, 1932. Copies of this publication have been widely distributed to agronomists and others interested in the question. A limited number of extra copies have been placed in the hands of President P. E. Brown and may be obtained from him upon request, as long as the supply lasts.

It is stated in the foreword of the report that it is possible some important references have been overlooked, and it is hoped that the present report will serve as a nucleus to which will be added supplementary evidence as it may be adduced. It was stated in our last report that it was the purpose of this committee to bring the first draft of the paper to the attention of this Society before final publication. In this way it was hoped to secure constructive criticisms and supplemental evidence which might have been incorporated in the final draft, but the exigencies of the situation made prompt publication imperative. It would be desirable to have the report revised in the light of additional evidence and published, about once every five years

This committee has within the past year further concerned itself with the question of fertilizer requirements of the most important crop plants of the United States, a question which has been discussed more or less in our reports of the past several years. In the last report a summary of a study of the literature on the ratio of nitrogen, phosphoric acid, and potash for the hay crop was presented. Similar studies of the nutrient requirement of the corn and cotton crops are under way. This committee hopes to prepare within a year a report which will show rather concisely the state of our knowledge in this field, evaluate methods, and make recommendations as to future procedure. With the idea of introducing some degree of standardization into projects with fertilizer ratios, and of offering the benefits of their study, the committee invites all persons or organizations considering experiments in this field to communicate with them before finally adopting a procedure.

H. J. Harper
M. F. Miller
F. E. Bear
B. L. Hartwell
A. B. Beaumont, *Chairman.*

FERTILIZER DISTRIBUTING MACHINERY

R. M. Salter, chairman, presented the report of the Committee on Fertilizer Distributing Machinery and upon motion it was adopted as follows:

The Committee on Fertilizer Distributing Machinery, working in cooperation with the Joint Committee on Fertilizer Application representing the National Fertilizer Association, the American Society of Agricultural Engineers, the National Association of Farm Equipment Manufacturers, and the American Society of Agronomy, reports as follows:

Machine application investigations have been conducted during the past year with corn, cotton, potatoes, beans, and sugar beets. These have included work in 21 states. The location of these experiments and the cooperation involved is outlined in Table 1.

A schedule of specific recommendations regarding (1) fertilizer placement for several important crops, (2) the design of fertilizer distributing machinery, and (3) future investigations needed was adopted by the Joint Committee and is presented herewith.

Recommendations of the Joint Committee on Fertilizer Application, November, 1932

The Joint Committee on Fertilizer Application is composed of official representatives of the American Society of Agronomy, the American Society of Agricultural Engineers, the National Association of Farm Equipment Manufacturers, and the National Fertilizer Association.

TABLE 1.—*Organization of projects on machine application of fertilizers, 1932.*

Location of experiment	Soil type	Cooperating agencies	Representatives in charge
		Beans (snap or green)	
1. Winter Garden, Fla	Leon fine sand	Bureau Chem. and Soils and Bureau Agr. Engineering, U. S. D. A.	J. J. Skinner, G. M. Bahrt and G. H. Serviss; G. A. Cumings, A. L. Sharp
2. Winter Garden, Fla	Leon fine sand		
3. Winter Garden, Fla	St. Johns sand		
4. Winter Garden, Fla	Leon fine sand		
5. Pompano, Fla	Leon fine sand		
6. Pompano, Fla	Leon fine sand		
7. Pompano, Fla	Leon fine sand		
		Beans (canning purposes)	
1. Geneva, N. Y.	Ontario silt loam	N. Y. State Agr. Exp. Sta. Bureau Agr. Engineering	C. B. Sayre G. A. Cumings
		Corn (in hill)	
1. Wooster, Ohio	Canfield silt loam	Ohio Agr. Exp. Sta.: Agronomy Dept. Agr. Engineering Dept.	R. M. Salter C. O. Reed
2. Lafayette, Ind	Brookston silt loam	Indiana Agr. Exp. Sta.: Agronomy Dept. Agr. Engineering Dept.	A. T. Wiancko R. H. Wileman
3. Lafayette, Ind	Brookston silt loam		
4. Columbia, Mo	Putnam silt loam	Missouri Agr. Exp. Sta.: Agr. Engineering Dept. Soils Dept.	M. M. Jones, D. D. Smith M. F. Miller
		Corn (sweet, drilled for canning purposes)	
1. Geneva, N. Y.	Ontario silt loam	N. Y. State Agr. Exp. Sta. Bureau Agr. Engineering	C. B. Sayre G. A. Cumings

		Cotton	
1. Clemson College, S. C.	Cecil sandy clay loam	Bureau Agr. Engineering	G. A. Cumings, W. H. Redit
2. Columbia, S. C.	Norfolk coarse sand	Bureau Chem. and Soils, and	J. J. Skinner, J. E. Adams
3. Florence, S. C.	Norfolk fine sandy loam	S. C. Agr. Exp. Sta.	H. P. Cooper, B. E. G. Prichard
		Bureau Agr. Engineering.	G. A. Cumings, A. L. Sharp
		National Fertilizer Assoc.,	H. R. Smalley, J. H. Stallings
		Joint Comm. on Fert. Applic.,	R. M. Salter
4. Rocky Mount, N. C	Norfolk sandy loam	with N. C. Agr. Exp. Sta.	H. B. Mann
5. Tifton, Ga.	Tifton sandy loam	with Ga. Coastal Plain Sta.	J. L. Stephens, S. A. Parham
6. State College, Miss	Ochlocknee fine sandy loam	with Miss. Agr. Exp. Sta.	J. F. O'Kelley, C. B. Anders
7. Marianna, Ark.	Lintonia silt loam	with Ark. Agr. Exp. Sta.	E. B. Whitaker, R. A. Cody
8. Baton Rouge, La.	Lintonia silt loam	with La. Agr. Exp. Sta.	A. H. Meyer, H. T. Barr
9. Nacogdoches, Texas.	Norfolk sandy loam	with Texas Agr. Exp. Sta.	H. P. Smith, H. F. Morris
10. College Station, Texas	Lufkin fine sandy loam	with Texas Agr. Exp. Sta.	H. P. Smith. H. F. Morris
11. Bryan, Texas.	Yahola clay	with Texas Agr. Exp. Sta.	H. P. Smith, H. F. Morris
12. Temple, Texas	Houston black clay	with Texas Agr. Exp. Sta.	H. P. Smith, H. Dunlavy
13. Lone Grove, Okla.	Calumet fine sandy loam	with Okla. Agr. Exp. Sta.	H. J. Harper, G. W. Statton
14. Stillwater, Okla.	Vernon sandy loam	with Okla. Agr Exp. Sta.	H. J. Harper, H. A. Daniel
		Potatoes	
		Bureau Chem. and Soils,	B. E. Brown
		Bureau Agr. Engineering,	G. A. Cumings
1. Onley, Va	Norfolk sandy loam	with Va. Truck Exp. Sta.	W. O. Strong
2. Cranbury, N. J	Sassafras loam	with N. J. Agr. Exp. Sta.	W. H. Martin
3. Presque Isle, Me.	Caribou loam	with Maine Agr. Exp. Sta.	J. A. Chucka
		with National Fert. Assoc.	Ove F. Jensen
4. Wooster, Ohio.	Canfield silt loam	and Ohio Agr. Exp. Sta.:	
		Horticulture Dept.	John Bushnell
		Agr. Engineer. Dept.	C. O. Reed
5. Greenville, Mich.	Montcalm sandy loam	and Mich. Agr. Exp. Sta.:	C. E. Millar, G. M. Grantham
		Sugar Beets	
1. Moorhead, Minn.	Fargo clay	Bureau Agr. Engineering,	E. M. Mervine
2. Scottsbluff, Nebr.	Minatare silt loam	Bureau Chem. and Soils,	L. A. Hurst
3. Fort Collins, Colo	Weld fine sandy loam	and	
4. Davis, Calif.	Yolo silt loam	Bureau Plant Industry	A. W. Skuderna

The following recommendations are based upon a coordinated study of the results of experiments in 34 states under a wide diversity of soil and climatic conditions. In recognition of the fundamental importance of economy in operations, as well as efficiency in placement, these recommendations apply to fertilizer applications made at the same time and in the same operation as planting. Where immediate adaptation of approved methods is impossible because of lack of suitable equipment, a suggestion to meet the temporary condition may be found as a concluding statement under the crop involved.

Fertilizer Placement

Corn

General. Hill or row application is superior to broadcast application of fertilizers for corn in most of the corn growing areas of the United States.

Hill-dropped or checked. When corn is hill-dropped, or check-planted, the fertilizer should be dropped at the hill and not drilled. The fertilizer is preferably placed in a band at each side of the seed and separated from it by a fertilizer-free layer of soil ½ to ¾ inch in thickness. Bands 1 inch or less in width are equivalent to wider bands for applications up to 200 pounds an acre of standard strength mixed fertilizers (around 20% total plant food). Bands 2 inches in width are equivalent to narrower bands at the lighter rates and safer at rates exceeding 200 pounds an acre. Bands 6 to 8 inches in length are preferable to those either shorter or longer. In regard to depth, the fertilizer is preferably placed within a zone extending from 1 inch below the seed to seed level or slightly above.

Drilled. The fertilizer is preferably placed in lateral bands approximately 1 inch wide, separated from the seed by ½ to ¾ inch of fertilizer-free soil, and located in a zone from 1 inch below the seed to seed level or slightly above. Uniform distribution along the row is essential for both safety and economy.

Cotton

Drilled. The preferred placement of fertilizer is in a band on each side of the seed, separated from it by 1½ to 2 inches of fertilizer-free soil and from 1 to 2 inches below the level of the seed. Uniform distribution along the row is essential for greatest efficiency.

Until machines are available to give this placement by a "once-over" operation, good results may be obtained under favorable moisture conditions from the common method of "bedding" on the fertilizer some time before planting. When this method is employed, care should be taken to place the fertilizer deep enough to insure at least 3 inches of fertilizer-free soil between the seed and the fertilizer.

Potatoes

Best results have been obtained with potatoes when the fertilizer is placed in a narrow band on each side of the seed piece, separated from it by 2 inches of fertilizer-free soil and in a depth zone from 2 inches below the seed to the seed level. When planting across sloping land the deeper placement is preferred. Uniform distribution along the row is essential for greatest efficiency.

Beans

For early fruiting and highest yield of snap or green beans the fertilizer should be placed in a band on each side of the seed, separated from it by 2 to 3 inches of fertilizer-free soil and in a depth zone from 1 to 2 inches below the seed level.

When cultural practices do not permit employing the placement recommended above, the fertilizer should be placed in a band at least 3 inches below the seed.

Sweet Potatoes

Fertilizers should be applied about 10 days after the plants are set in a band 12 to 18 inches wide on the surface of the ground over the plant row and harrowed into the surface soil. An alternate method giving practically the same placement is to apply the fertilizer on both sides of the row with a cultivator fertilizer attachment at the first cultivation.

Small Grains

The fertilizers usually used on small grains are more effective when drilled with the ordinary equipment at seeding time than when applied broadcast or

drilled in a separate operation. Information on the placement of highly soluble fertilizers used at heavy rates of application is lacking.

Fertilizer Distributing Machinery

It is recommended that manufacturers of fertilizer distributing machinery give careful consideration to design and to the use of manufacturing materials as suggested to meet the following requirements:

Quantities Delivered

Range. Sufficient range for delivery of the quantities of fertilizers of varying concentration that are ordinarily applied should be provided.

Accuracy of adjustment. Obtainment of desired quantities is greatly facilitated by provision for small intervals of movement of the regulating device through an adequate range. For sliding adjustments marked reference points such as distinct graduations, or notches are essential.

Constancy. Variations in quantities delivered at any given setting may be minimized by (a) less dependence on gravitational flow which varies according to changes in the physical condition of the fertilizer and depth of material in the hopper. (b) Prevention of deposits in the delivery opening which materially reduce the flow, particularly when the fertilizer is metered through a narrow slit. (c) Elimination of, or compensation for, variation in flow due to changes in the angle of inclination of the machine. These changes occur principally on sloping land, but may occur on level land with walking-type machines not equipped with effective supports or depth gages. (d) Elimination of any uncontrolled movement of quantity-regulating gates. In some machines, variations in flow may amount to 25% plus or minus, when the adjustment is reset to the same dial reading.

Irreregular distribution along the row as distinguished from variations in the average quantities delivered per row or acre may be eliminated to a great extent through the use of refined dispensing mechanisms and compensating devices or arrangements for those machines which inherently produce variations at regular intervals.

Approved Relative Placement of Fertilizer and Seed

Corn planter attachment. To place fertilizer in a lateral band on each side of the hill of hill-dropped corn, or on each side of the row of drilled corn, as recommended, the fertilizer depositor of the corn planter should carry a deflector, or similar device, to split the fertilizer stream into halves, and a hood, or similar device, to hold away the incoming soil until the fertilizer has reached the bottom of the furrow. It seems advantageous to permit a little soil to cover the seed while the kernels are still under the protection of the deflector; also to slope the faces of the hood so that a part of the in-coming soil will drop downward into place instead of all of it moving laterally to complete the covering operation.

Potato planter attachment. To drill the fertilizer in a band at each side of the row, as recommended, the use of two common disk furrow-openers is highly successful. Tubes or boots of adequate size to prevent clogging should be mounted in a manner that will insure delivery to the bottom of the fertilizer furrow.

Cotton and bean planter attachments. To place the fertilizer at the sides of the seed as recommended for cotton and for snap beans, development and adaptation of suitable placement devices will be required which in some instances may also necessitate new general designs of the planters.

Resistance to Corrosion

Difficulties with those parts whose movement, strength, or life is readily affected by corrosion would be obviated by the use of metal alloys highly resistant to corrosion. Corrosion which is ordinarily greatly accelerated in the presence of fertilizer materials, frequently interferes with the movement of close fitting parts, and adjustment especially of certain quantity regulating devices.

Ease of Cleaning and Adjustment

Cleaning. To be readily accessible for thorough cleaning, distributors must be of simple design, or designed to permit tilting, removal, or exposure of the hopper and dispensing mechanism. Thorough cleaning and proper protection are recognized as essential to the prevention of excessive corrosion as well as

breakage which frequently occurs when fertilizer hardens and is not removed from the dispensing mechanism.

Adjustment. For greatest convenience, adjustment should be easily accessible and changing should not require partial disassembly.

General

It is recommended that application studies be continued on crops covered by the foregoing paragraphs, and that further work be carried on or new work be inaugurated with the following crops: Sugar beets, tobacco, small grains, root crops, canning peas, tomatoes, cabbage, melons, and other important vegetable crops.

To give farmers and manufacturers full and immediate advantage of the findings of the extensive experimental work to date so that the grower may net a greater return for each dollar he invests in fertilizer and in fertilizing distributing machinery, it is suggested that a copy of these recommendations be sent to the farm press, to the farm machinery trade press, to extension directors, to county agents, and to soils, crops, and agricultural engineering extension specialists, to manufacturers of fertilizer distributing machinery, and to fertilizer manufacturers.

It is suggested that the Society again appoint a committee to continue the work.

V. R. FAIR	J. J. SKINNER
A. H. MEYER	E. TRUOG
C. O. ROST	R. M. SALTER, *Chairman.*

CORN BORER INVESTIGATIONS

L. E. Call, chairman, presented the report of the joint Committee on Corn Borer Investigations and upon motion it was accepted as follows:

Owing to weather conditions which were adverse to the flight of the European corn borer moths, very little additional spread of the insect occurred in 1932. New infestations were found in nine townships in Indiana, six townships in Maryland, one township in Kentucky, three townships in Pennsylvania, and two townships in Virginia. The present known infested area includes the states of Wisconsin, Michigan, Indiana, Kentucky, Ohio, West Virginia, Pennsylvania, New York, New Jersey, Maryland, Virginia, Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, and all of the corn-growing area in Canada except the western provinces. The two-generation strain of borer is known to be present in Maine, New Hampshire, Massachusetts, Connecticut, Rhode Island, Virginia, Maryland, and parts of New Jersey and New York, and in Canada, Nova Scotia, and New Brunswick. So far as known the one-generation strain of borer occurs in the remainder of the infested area.

The increase in borer population in 1932 again emphasizes that the European corn borer is one of the most potentially destructive crop pests ever introduced into America. This fact calls for the continued cooperation of the farmer, the scientist, the educator, and all state and federal administrative officials.

The joint committee of entomologists, agronomists, agricultural engineers, agricultural economists, and animal husbandmen commends the efforts of all farmers practicing recommended control measures and of those engaged in the research, regulatory, and educational activities.

In considering the progress and value of corn borer investigations it should be noted that many of the results of these investigations have an immediate application in the betterment of agricultural practices, regardless of the corn borer.

The committee recognizes the necessity for the continuation of the research, educational and regulatory programs of the state and federal governments,

and earnestly recommends the appropriation of the funds needed to maintain them as suggested later in this report. The committee recommends this support only after due consideration of the absolute necessity of holding current governmental expenditures to a minimum.

1. We reiterate our belief in the value of the federal quarantine regulations which have undoubtedly been instrumental in preventing long distance spread of the insect and regret that funds were not made available for their continuance in the United States. To provide the information necessary as a basis for present and future state regulations and to aid in parasite introductions and other general control operations it is urged that thorough scouting and infestation survey activities be continued and that funds be made available for this work. We recommend that the Canadian government continue its federal and provincial quarantine regulations which have proven of great value in the past.

2. That the educational agencies of the Federal governments of the United States and Canada and of the State and Provincial agricultural colleges, continue their programs relating to the corn borer, particularly where control programs are being conducted, extending these to conform with the spread and abundance of the insect and with the increased knowledge gained through research.

3. The entomological investigations now in progress should be continued. The following studies on which material progress already has been made, should be especially stressed: The recolonization of those species of parasites already established in the United States which occur in numbers sufficient for this purpose and the collection and introduction of all other species of possible benefit in reducing infestation; the development of effective insecticides and their efficient application; and the evaluation of the effect of environmental factors on the corn borer.

4. While the development of immune varieties seems unlikely at this time, experiments point clearly to the probable development of high yielding resistant and tolerant varieties of corn which should be an important factor in control. To promote the development of such varieties, the corn breeding programs of the State and Federal governments should be continued and steps taken to correlate more effectively the work of the various agencies.

5. Inasmuch as control of the borer, as yet, depends largely upon mechanical means in the hands of growers, it is recommended that research and development work along mechanical lines by the agricultural engineers be continued and be strongly supported by the Federal Government and by the States, with a sincere effort being made to coordinate such activities through the Bureau of Agricultural Engineering. In such work it is recommended that attention should be directed first toward machine types now common on farms, in view of the fact that agriculture cannot easily avail itself of new types of equipment primarily for control until it has used to the best possible advantage the equipment now on farms.

The manufacturers are to be commended for their interest and loyal support in corn-borer work to date, and, in spite of the readjustment period, it is hoped that they will continue rapidly to convert development accomplishments into the commercial channels, so that the growers—who must carry the burden of control—will not be handicapped by the latest, practical, mechanical devices not being available to the public.

6. Since the corn borer control practices developed and proposed may change the organization and income of the farm it is important that the relation of these practices to the entire farm business be determined and recommendations made for specific conditions. Proposals including changes in cropping systems, complete utilization of corn, substitute crops, changes in corn acreages, and labor and equipment costs should be worked out in line with the objective of maximum returns from farming.

7. In view of the continued increase in the intensity and spread of European corn borer infestation during the past year, the committee recommends a continuance of studies to determine the influence of different borer populations on the feeding value of corn and the corn plant in different forms, the yield of feed nutrients per acre, and the influence of the corn borer and approved control measures upon the cost of production and quality of livestock products.

Respectfully submitted,

American Association of Economic Entomologists:

G. A. Dean — D. J. Caffrey
L. Caesar — T. J. Headlee
J. J. Davis

American Society of Agronomy:

L. E. Call — J. F. Cox
W. L. Burlison — R. M. Salter
F. D. Richey

American Society of Agricultural Engineers:

R. D. Barden — R. M. Merrill
C. O. Reed — A. L. Young
W. C. Harrington — R. H. Wileman

American Farm Economic Association:

E. D. Hill — J. Coke
C. R. Arnold — Lynn Robertson
C. L. Holmes — R. R. Hudelson

American Society of Animal Production:

E. W. Sheets — Paul Gerlaugh
F. G. King — G. A. Brown
F. B. Morrison

PUBLICATIONS OF THE SOCIETY

C. W. Warburton, chairman, presented the report of the Committee on Publications of the Society and upon motion the report was accepted as follows:

Your committee has given consideration to the publications situation as reported by the Editor of the Journal of the American Society of Agronomy. The reduced funds available to the U. S. Dept. of Agriculture and to the experiment stations for publication of bulletins and circulars will result in increased pressure on technical journals for publication therein of the results of experimental work. The committee has also given consideration to the desire of many members of the Society for a soils journal and the interest of a considerable group in a fertilizer journal. Under present financial conditions, however, it is impossible to attempt the issuance of a new journal by the Society or even to expand the one now published.

The committee suggests to the Editorial Board the possibility of the issuance of one or perhaps two abstract numbers during the year, containing not only the abstracts of papers presented at the annual meeting but abstracts of other papers submitted for publication but which, under present conditions, it is not possible to print in full. The Committee plans to give further consideration to the publication situation and probably will submit several propositions to the membership of the Society for consideration and advice within the next few months. It is expected that this inquiry will be sent out in the form of an insert in the Journal in order to save postage costs.

Respectfully submitted,

J. G. Lipman — J. D. Luckett, *ex-officio*
W. L. Slate, Jr. — C. W. Warburton, *Chairman*.

LAND UTILIZATION

J. G. Lipman, chairman, presented the report of the Committee on Land Utilization which, upon motion, was accepted as follows:

The National Land-Use Planning Committee has outlined a satisfactory program and has made a very promising beginning in dealing with the task assigned to it. We should not underestimate either the magnitude or the importance of this task, for it concerns a problem so significant and far reaching as to call for the sympathetic interest and support of every public spirited person. There is no doubt that the American Society of Agronomy will give to the National Land-Use Planning Committee its fullest cooperation. It is to be hoped that this cooperation will make, in some measure at least, the labors of the Committee less difficult and more effective. To that end, this report is being offered not in any sense as a detailed study of land utilization in the United States, but, rather, as a general statement on the major questions which directly concern this particular problem.

In the large, there are three types of land which should be differentiated in any general study of land utilization. The three types of land consists of (a) non-agricultural; (b) potentially agricultural; and (c) agricultural land. The surveys already completed, those now in progress, and others still to be made, will readily furnish a basis for the proposed differentiation. In the first place, we should indicate the limits and boundaries of land which is clearly non-agricultural and should propose methods for dealing with this land. The needs of soil conservation, forestry, protection of wild life, flood control and water conservation and recreation should be provided for in planning the present and future use of our non-agricultural land.

The potentially agricultural land must, of necessity, represent a variable quantity. The area of this land will expand with rising prices of agricultural commodities, population shifts and improved transportation and distribution facilities. It will also vary in extent through influences both economic and social originating outside of the United States. Insofar as the needs of our own population are concerned, there is no reason to anticipate any marked change of potentially agricultural to crop land. On the other hand, if the volume of our agricultural exports is substantially increased, or there develop an increased demand for agricultural raw materials in our industries, some of the potentially agricultural land may be transferred to the class of crop land.

According to the census of 1930, our land in farms represented a total in round millions of 986,000,000 acres. This was divided into about 413,000,000 acres of crop land, 464,000,000 acres of pasture land, and somewhat less than 65,000,000 acres of woodland not used for pasture. Of the total acreage of crop land, there were only 359,000,000 acres harvested. The rest consisted of more than 12,000,000 acres of crop failure and more than 40,000,000 acres of idle or fallow land. It is well known that our crop land includes some that is marginal and sub-marginal. The exact acreage of these two classes of land is not known. At best, it is a variable quantity fluctuating in area with the rise and fall of price levels. An inquiry addressed by the Chairman of your Committee to the Agronomists of the different states failed to bring forth complete information on this subject. Nevertheless, it has been indicated that much land now used for farming purposes is not remunerative even under normal economic conditions. In the New England States, for instance, where land is used more fully than it is in most other sections of the United States, there are not far from 3,000,000 acres of land regarded as marginal. In addition, there are more than 500,000 acres that are unquestionably sub-marginal. Despite the fact that the information at hand is quite incomplete, we have a record of about 60,000,000 acres designated as marginal and of about 120,000,000 acres designated as sub-marginal

by the Agronomists of the states that had any information to offer on the subject. It seems reasonable to assume, therefore, that while the non-agricultural land is a more or less definite quantity, the potentially agricultural land will be increased or decreased with changing conditions. On the whole, it is destined to expand rather than contract in area since it is to receive accessions from land now used for crop purposes.

It is obvious that the agronomists of the several states can render an effective service to the National Land-Use Committee by arranging for a thoroughgoing study of the land resources of their respective states. There will need to be set up in each state a group of persons who could collaborate and organize the necessary information as a basis for classifying and grouping land of different types and for outlining a program of land use. It would be helpful if the agronomists could secure the cooperation of geologists, engineers, economists and sociologists toward the development of an adequate land use program. The preparation of the program will be facilitated when due consideration is given to the historical background of land use in any given region. An analysis of the past and present trends of land use will facilitate a more accurate forecast of future trends.

Factors of Adjustment

Among the more important factors which must enter into the consideration of our problems are (a) population; (b) standards of living; (c) minimizing losses in the production, transportation, and storing of food products; (d) transportation and distribution economics; (e) part-time farming; (f) imports and exports; (g) demand for industrial raw materials derived from the land; (h) forestation, water conservation, and protection of wild life; and (i) recreation.

Recent studies of population trends and vital statistics show conclusively that in another decade or two our population will have reached its maximum size. On the other hand, mechanization will tend to reduce further the number of work animals. More effective methods for protecting growing crops against damage by insects, fungi and bacteria and likewise better methods of refrigeration, processing and storing will indirectly increase the volume of agricultural commodities and to that extent make possible a reduction in the crop acreage. There is no reason to anticipate, therefore, that more land will be required in the future for the growing of crops. On the other hand, higher standards of living, more varied dietaries, and an expanding demand for carbohydrates, proteins, gums and waxes as industrial raw materials will tend to increase the acreage under cultivation. We must also consider the part to be played by improved methods of soil management and the very marked increase in production per given area wherever the climatic conditions are favorable. Due consideration of the several factors just noted will lead to the conclusion that we ned not expect a substantial expansion in the acreage of crop land insofar as domestic needs are concerned. On the other hand, we must provide a place in our program for the shifts in production areas as a result of changes in population, the decentralization of industries and the rationalization of transportation and distribution. We shall need to reckon also with trade arrangements whereby there will be less impediment to the flow of agricultural commodities from one country to another and especially the interchange of agricultural products between regions in the tropical and temperate zones. Finally, we shall need to provide in a more systematic way for the production of timber, of game, and of fish. These will become a more prominent feature of our land use problems.

National and International Planning

We seem to be coming into a new economic and social era. If idealism is not enough of a moving force to bring about international good will and prosperity, the logic of enlightened self-interest will compel such readjustments of land use as to lessen, if not eliminate, destructive competition and the impoverishment of agriculture in different countries. Consideration will need to be given to the following: (a) The distribution of agricultural production, both domestic and foreign; (b) surplus and deficiency areas; (c) present and potential dietaries; (d) the pooling of land resources; (e) production programs; (f) livestock and livestock products; (g) food conservation and processing; and (h) safety margins in production.

At the present time, there are economic clashes not only between competing countries but economic aggression often equivalent to economic warfare between different classes of population within the same country. Industrial nations attempt to become self-sufficient by subsidizing their agriculture. High tariff walls are the usual expedient to this end. As a result, the cost of food and of other agricultural raw materials within that country increases to a point where wages and other manufacturing costs go up. This in turn makes it more difficult for the industrialist to hold his own in the markets of the world. Industrial efficiency and free trade in agricultural commodities would seem to be the most desirable economic structure for countries of this type. But there are other factors that enter into the situation, particularly those of a political and social character. Thus mankind is learning by the method of trial and error and at the cost of much suffering and distress that no country is sufficient unto itself. Lest this report become unduly long, a discussion of the other points noted above will not be attempted at this time.

Fact-Finding Programs

The members of this Society are in a position to furnish the stimulus and leadership toward expediting the studies and investigations essential as a basis of enlightened land policies. Attention should be directed to planned studies dealing with the following: (a) Surveys, classification, and mapping of soils; (b) physical and chemical defects of soils and their correction; (c) sources and supplies of lime, chemical fertilizers, and of other materials required for raising yield levels; (d) reclamation methods and practices; (e) systems of soil management; (f) systems of farming and of cost accounting; (g) the making available of superior plants and animals; (h) more adequate protection of plants and animals against pests and parasites; (i) sources and use of power; (j) drying, refrigeration, canning, fermentation, and other methods of processing; (k) economic and social factors related to the use of land; and (l) definite methods for the best use of any given type of land in any given location.

Much information on these subjects is already available. It should be made more complete and should be so organized as to permit the more speedy outlining of land use problems in the several regions and the modification of such local programs into an effective national program. The more effective and intelligent the local efforts, the better and more adequate will be our national program of land use.

Education

The best plans and programs are certain to fail if the men and women on our farms lack the general and vocational education requisite for the establish-

ment of successful farming. The findings of our technicians will become fruitful only to the extent to which they are understood and used by the rank and file of our farmers. Hence, our research programs should be coordinated with our teaching programs in order that every individual may be able to obtain the training best suited to his capacity. Provision should thus be made for vocational instruction, for the more general education and for the maintenance of an informational and advisory service which would assure to us the most effective use of the land.

Recommendations

This brief report may be concluded by placing before you the following recommendations:

1. That the Society appoint a committee to cooperate with the National Land-Use Committee.
2. That it ask the agronomists in each state to assume the initiative in urging that a Land-Use Planning Committee be appointed and be made to function.
3. That State Land-Use Planning Committees coordinate their activities through the general committee of the Society.
4. That public interest in land-use programs be stimulated.
5. That the American Society of Agronomy respectfully ask the President of the United States to arrange for an International Land-Use Conference.

Respectfully submitted,

C. F. Marbut W. L. Burlison
C. G. Williams J. G. Lipman, *Chairman*
N. E. Winters

SOIL EROSION

H. H. Bennett, chairman, presented the report of the Committee on Soil Erosion which, upon motion, was accepted as follows:

Your committee on soil erosion has been offered a considerable number of good suggestions for presentation to the Society. Unfortunately, these can not all be included in the present brief report.

It has been suggested, for example, that we report on new lines of research in the field of erosion investigations. We are preparing to put out as quickly as possible both mimeographed and published reports which will present all phases of the work pertaining to the national program of soil conservation recently inaugurated by the U. S. Department of Agriculture and the states cooperating.

It has been suggested that a bibliography on erosion be prepared at once. We have made considerable progress along this line and will get out such a mimeographed bibliography, at least a preliminary one, within the next few months.

It has been suggested that we stress the educational phases of erosion work. One of the members of the committee recently gave a series of lectures on erosion to the vocational teachers of a state where erosion is the most pressing problem pertaining to the physical side of land use. These lectures ran at the rate of two a day, three hours each, at points separated by an average distance of about 100 miles, and were illustrated by profile samples of the principal erosive soils of each locality. An agricultural engineer followed up the lectures with field instruction in the actual laying out and building of terraces of the most approved types, as indicated by experiments at the regional erosion stations.

In further respect to the educational campaign a considerable number of technical, semi-technical and popular articles pertaining to various phases of erosional processes and erosion-control measures have appeared in a variety of publications during the present year; scores of brief articles have gone out to the metropolitan and rural newspapers of the country; there have been numerous discussions of the subject before a variety of groups in many parts of the country, and a number of radio broadcasts have passed out over national and regional hook-ups.

It occurs to this Committee that a brief statement pertaining to some features of progress resulting from the national program of soil erosion research would be of interest to agronomists. Pertinent results are coming in rapidly—fundamental results of vital importance to a clear understanding of erosion processes, extent and geographical distribution of land damage by erosion, and methods of control. Unmistakable evidence is piling up to the effect that the original plan for carrying out the erosion research program on a regional basis was the proper course to pursue. A few basic findings are as follows:

1. Not less than 75% of all the cultivated land of the country is subject to damage by erosion in some degree. This conclusion is based upon (a) the findings of the nation-wide reconnaissance erosion survey, which is proceeding slowly but persistently, together with regional and very intensive local erosion surveys; (b) examination of topographic and soil maps; and (c) quantitative measurements of soil losses from slopes ranging from level to land too steep for safe cultivation.

2. Erosion rates are enormously affected by (a) degree of slope, (b) type of soil, (c) kind of cover, (d) type of use, and (e) character of precipitation. In less degree length of slope also affects the rate.

3. Vegetation of all kinds tested slows down erosion. The thicker growing crops are the more effective

4. Every ground cover of vegetative litter thus far tested exerts a powerful influence toward the diminution of erosion. The most effective cover, according to present measurements, is the accumulated humus cover on the floor of forests which have not been repeatedly burned. After this, the thick-growing crops, such as grass, alfalfa and lespedeza, are most effective. An example may be taken from the results obtained at the Red Plains Station in central Oklahoma: To date, unburned land of the Vernon fine sandy loam type, forested with post oak and black-jack, has lost 15 times less soil and 30 times less of the precipitation, as runoff, than burned-over forest land of the same soil, cover and slope, immediately alongside. During the same period the soil and water losses from a good sod of Bermuda have exceeded the losses from the unburned area by 4 and 20 times, respectively. The losses from continuous cotton have been 1,460 times greater with respect to soil and 165 times greater with respect to water.

The trend of losses have been in the same direction at other regional erosion stations.

5. In every measurement where organic matter has been incorporated with the soil, erosion has been reduced to a very considerable degree.

6. In every measurement where crop rotations have been practiced, erosion has been materially reduced.

7. Strip cropping has largely cut down erosion, with respect to both wind and water.

8. Scarification of fields with a waffle-iron hole digger has largely reduced soil losses. Fall-plowed ground left in as cloddy a condition as practicable has been found less erosive than finely pulverized soil, as pertaining to the activities of both wind and water.

9. Running of rows along the contours, rather than up-and-down the slopes, has greatly reduced erosion and runoff.

10. Measurements from terraced areas show that the amount of soil leaving the fields is enormously reduced where the terraces have been properly made.

11. Cover crops have greatly minimized soil wastage by erosion.

12. Cheap grass dams, brush dams, rock dams, wire dams, log dams and willow and black locust dams properly placed have effectively controlled small gullies. The plowing down of the sides of gullies and the planting of these with black

locusts, grass, buckbrush, willow and honeysuckle, have made it possible to control gullies at small cost. Diversion of water from the heads and sides of undercutting gullies with the type of embankment used in field terraces is proving an effective control measure.

13. Erosion-control measures can be effectively employed upon much steeper slopes where erosion comes largely from melting snow.

14. The lateritic soils are less erosive, on comparable slopes or even steeper slopes in some instances, than soils of the same texture belonging to the non-lateritic group.

15. Gravelly and stony soils in general are much less erosive than gravel-free and stone-free soils of the same series, occupying the same degree of slope.

16. Within certain limits erosion increases with the length of slope, but not proportionately. This phase of erosion procedure involves processes of loading and unloading of the silt burden, even on uniform slopes, and these processes vary greatly with the soil.

17. Erosion varies with the season and to a tremendous extent with the character of rainfall.

18. Erosion proceeds faster after the topsoil is removed, in the case of most of the soils studied.

19. Erosion-exposed clay subsoils are much less productive than uneroded soil, even where the topsoil consists of clay. Such "raw" clay is much more difficult to till. Crops suffer on it more during dry periods, the moisture contained being less available to plants. The quality of some crops is markedly reduced when grown on land whose topsoil has been washed off, as in the instance of both the lint and seed of cotton grown on Vernon fine sandy loam (which, with its close relatives, is representative of about one-third to one-half of the 30 million acres comprised in the Red Plains of Oklahoma and Texas).

20. Removal of the topsoil greatly affects the character of vegetation coming in after abandonment. Recovery from these radical changes is very slow on some soils. The proportion of bare ground is greatly increased, as a rule, and the returning vegetation is of an inferior character, weeds or poverty grass taking the place of useful grasses over vast areas. In some instances not a single species of the virgin cover has been found on eroded areas of the Great Plains, after three years of abandonment.

21. Soil structure seems to affect erosion more than soil texture, at least with some important types. The structural efficiency of a soil, as relating to disposal of rainwater through or within the body of the soil, is reduced as the top layers are planed off.

22. In some localities the older farmers take more interest in the erosion problem than the younger men. This may be because it takes more time for a man to comprehend the impoverishing effects of the process.

23. In connection with the development of technical equipment, the Uhland Divisor, worked out by Mr. R. E. Uhland of the Bethany, Missouri Erosion Station, will greatly facilitate measurements of runoff and washoff by taking directly from plots aliquot samples. Divisors with silt box attachments have been perfected by Mr. H. V. Geib of the Temple, Texas Erosion Station and Mr. G. W. Musgrave of the Clarinda, Iowa Erosion Station. These will greatly reduce the cost of measuring runoff and washoff from plots and make possible the handling of larger plots than can be handled with the tank method of catching all the runoff and washoff. These divisors have all undergone rigid calibration tests. Descriptions of them are to be published at the earliest possible moment.

Various other useful devices have been developed, which can not be specifically referred to in this brief report.

24. In spite of all we have done in this country in the direction of improved seed, improved cultivation, increased use of improved farm machinery, increased use of fertilizers, soil-improving crops and crop rotations, coupled with a vast amount of education in schools and colleges and with books, bulletins, papers, magazines and field instruction by crop specialists, the yield of some of our major crops has not increased. Corn, for example, a crop which has not spread out into dry-land areas on any large scale, and which has not suffered tremendously from disastrous plant-disease or insect scourges, produced at the rate of 27.09 bushels per acre for the decade 1871 to 1880, inclusive, and at the rate of 26.13 bushels for the period 1921 to 1930 inclusive. The maximum and minimum year yields for the first period were, respectively, greater and less than the cor-

responding yields for the second period. It is difficult to explain this loss on any basis but the impoverishing effects of erosion.

In conclusion, your committee respectfully recommends that the committee on soil erosion be continued.

Respectfully submitted,

A. B. CONNER
H. H. KRUSEKOPF
W. B. COBB
F. L. DULEY
H. H. BENNETT, *Chairman.*

RADIO IN EDUCATION

O. S. Fisher, chairman, presented the report of the Committee appointed to represent the Society on the National Advisory Council on Radio in Education which, upon motion, was adopted as follows:

After endeavoring for several months to make proper contacts with the National Advisory Council on Radio in Education, your committee came to the conclusion that inasmuch as the members of this organization were composed almost entirely of members of the agronomy departments of the various agricultural colleges, experiment stations, and the U. S. Department of Agriculture, that it would seem wise and proper if we would cooperate with the federal and state governments in the radio broadcasting work that is already organized and has access to practically a nation-wide chain of broadcasting stations every week day.

Through Mr. Salisbury of the Radio Service of the Department of Agriculture, we were offered the use of this service through the National Farm and Home Hour for a 30-minute broadcast at such a time as would be most convenient to the American Society of Agronomy.

This information was given to your President and, with his approval, your committee has planned a program which will appear tomorrow at 12:45 as a part of the National Farm and Home Hour, and sponsored by the American Society of Agronomy. This program is to be broadcast over 48 stations, reaching all the states as far west as Denver, giving us the opportunity of talking over the widest chain of stations giving free access to the government and state institutions at this time.

This broadcast, the program of which appears on the last page of the official program this year, was arranged with the thought of being in the nature of a part of the Twenty-fifth Anniversary of the American Society of Agronomy. After considerable correspondence we were able to secure our President, Dr. Brown, and Dr. Lipman of New Jersey to discuss the work of the American Society of Agronomy from the standpoint of soils, Dr. Hayes of Minnesota to discuss the work with crops, and Director Warburton of the Extension Service of the Department to summarize the work from the angle of extension.

Respectfully submitted,

S. C. SALMON
E. L. WORTHEN
H. C. RATHER
P. H. STEWART
O. S. FISHER, *Chairman.*

STUDENT SECTIONS

The report of the Committee on Organization of Student Sections of the Society was presented in the absence of the chairman, E. R. Henson. Upon motion the recommendations of the Committee were approved as follows:

The special committee to consider the organization of a Student Section of

the American Society of Agronomy met during the summer meeting of the Corn Belt Section of the Society at Madison, Wis., after having obtained the reactions of students to the proposed organization at Minnesota, Nebraska, Illinois, and Iowa.

Students in agronomy and related fields have very favorably received the suggestion of a national student organization to be affiliated with the American Society of Agronomy as a Student Section. Students believe that membership in such a national organization will stimulate their interest in the field of agronomy. A circular letter to agronomists recently mailed has brought 12 favorable replies with none against the proposed organization.

The committee approved the form of organization used at Iowa State College in a temporary organization, but felt that the definite plan of the student organization should be left to the student sections with the assistance of a committee from the American Society of Agronomy.

The committee recommends that the American Society of Agronomy authorize the organization of a Student Section of the Society to be composed of students in farm crops and soils and in related fields.

The committee further recommends that a committtee be appointed from the Society to proceed with the organization and direction of a Student Section of the Society.

Respectfully submitted,

F. D. Keim — H. K. Wilson
J. W. Zahnley — E. R. Henson, *Chairman.*
G. H. Dungan

NITROGEN RESEARCH AWARD

M. M. McCool, Chairman, stated that the Committee on the Nitrogen Research Award had made all arrangements to make an award, having spent much time in making a selection, but had been very recently advised that the Chilean Nitrate of Soda Educational Bureau was unable to provide the funds for the award this year.

ORGANIZATION OF THE SOILS SECTION

M. F. Millar, chairman, reported on the organization of the Soils Section of the Society and upon motion the report was accepted as follows:

A meeting of the Soils Section of the Society was called to order by the chairman of the Organizing Committee at the Willard Hotel, Washington, D. C., November 17, 1932. A nominating committee was appointed consisting of M. F. Morgan, chairman, L. D. Baver, and S. D. Conner. The organizing committee, consisting of S. A. Waksman, R. I. Throckmorton, M. F. Morgan, and M. F. Miller, *Chairman*, presented a proposed set of by-laws for governing the Section. The by-laws as submitted were approved with the exception that the section providing for the Soils Section to function as the American Section of the International Society of Soil Science was amended to include the statement that "only those members paying the regular dues of the International Society shall have a vote in matters pertaining to it." The by-laws as amended and adopted accompany these minutes.

The chairman called attention to a suggestion of Dr. J. G. Lipman, that it might be possible to secure the approval of the executive committee of the International Society of Soil Science of a plan to recognize those members of the Soils Section who do not pay the International dues as associate members of the

International organization. A motion was made and carried that the executive committee take up this matter with Dr. Lipman and secure his assistance in attempting to bring about such action by the International Society.

The nominating committee reported the names of Richard Bradfield for *Chairman* and C. E. Millar for *Secretary* of the Section for the ensuing year. On motion the report of the committee was approved and the nominees were duly elected.

After certain announcements regarding matters pertaining to the International Society of Soil Science the meeting adjourned.

As no secretary was appointed for this session the *Chairman* of the Organizing Committee prepared and signed this report.

BY-LAWS OF THE SOILS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

1. No annual dues shall be required of members of the Section, excepting those paid to the Society.

2. The Section shall hold one program each year, at the time of the regular meeting of the Society, but additional regional or special programs may be held if sufficient demand exists and provided such meetings are approved by the Executive Committee of the Society.

3. One business meeting of the Section shall be held each year at the time of the regular meeting of the Society.

4. The officers of the Section shall consist of a chairman and a secretary, elected at the annual business meeting of the Section, to serve for one year.

5. The Section may provide for one or more sub-sections, through a two-thirds vote of the members of the Section present at any annual meeting, provided advance notice of such proposed action is published in the JOURNAL of the Society.

6. The officers of the Section, together with the chairmen of sub-sections as may be formed, shall constitute the executive committee.

7. The Section may provide for such additional committees as may be necessary.

8. The duties of the sectional officers shall be those usually pertaining to their respective offices and in addition they shall be charged with the preparation of the annual program, either directly or with the assistance of a program committee to be appointed by the chairman, which committee shall include representatives of such sub-sections as may be formed.

9. The Section shall function as the American Section of the International Society of Soil Science, but only those members paying the regular dues to the International Society shall have a vote in matters pertaining to it.

10 These by-laws may be amended by a two-thirds vote of the members present at any regular business meeting of the Section, provided advance notice of such amendment or amendments is published in the JOURNAL of the Society.

Respectfully submitted,

S. A. WAKSMAN — M. F. MORGAN
R. I. THROCKMORTON — M. F. MILLER, *Chairman.*

ORGANIZATION OF THE CROPS SECTION

R. J. Garber, chairman, reported on the Organization of the Crops Section and upon motion the report was accepted as follows:

Inasmuch as the main purpose of forming a Crops Section of the American Society of Agronomy is to facilitate program building, your committee makes the following recommendations:

Officers.—The officers of the Crops Section shall consist of the chairman and two members who shall constitute the program committee. The chairman may designate one of the members to act as secretary if it seems desirable.

Election.—The officers of the section shall be elected each year during the first meeting of the Crops Section at the time of the annual meeting of the American Society of Agronomy. Nominations shall be placed before the Section by a nominating committee of three, appointed by the chairman of the Section. Nomination may also be made from the floor. In selecting officers it is suggested that geographic representation be kept in mind.

Duties.—It will be the duty of the officers of the Section to prepare a program for the annual meeting next following their election and to facilitate the handling of any other business which may come before the Section. The chairman or his representative will preside at the Sectional meetings.

Respectfully submitted,

M. A. McCall
George Stewart
R. J. Garber, *Chairman.*

RESOLUTIONS

S. B. Haskell, chairman, reported for the Committee on Resolutions and upon motion the report was accepted as follows:

For several years it was customary to publish in the Journal from time to time brief memorials on the life and work of deceased members of the Society. With the appointment in 1931 of a standing committee on Resolutions it was conceived that one of the duties of this committee would be to take cognizance of the passing of members of the Society and of others who had made notable contributions in the fields of science related to agronomy. Hence, it is our sad duty to note at this time the passing during the year of seven men, four of them members of this Society. These are Dr. N. A. Cobb, who died in Baltimore, Md., June 4, 1932; Professor K. K. Gedroiz, who died in Moscow, U. S. S. R., on October 5, 1932; Dr. W. P. Headden, who died at Fort Collins, Colorado, on February 5, 1932; Dr. George Janssen, who died on January 31, 1932; Professor T. C. Johnson, who died in Norfolk, Virginia, on March 31, 1932; Dr. J. O. Morgan, who died at College Station, Texas, October 8, 1932; and H. W. Warner, who died in Wilmington, Delaware, on June 12, 1932.

The following brief statements relating to the life and work of each of these men have been prepared by those closely associated with them or well qualified to evaluate their contributions to agronomy.

Nathan Augustus Cobb

1859–1932

Dr. N. A. Cobb, Principal Nematologist of the Bureau of Plant Industry, U. S. Dept. of Agriculture, died on June 4, 1932 at the Johns Hopkins Hospital in Baltimore, Maryland, where he had gone for his annual health examination. A sudden heart attack ended the life of this eminent scientist, whose splendid physique and mentality so greatly betrayed his age. Dr. Cobb was born June 30, 1859, in Spencer, Massachusetts. He graduated from the Worcester Polytechnic Institute, and shortly after graduation was appointed professor of chemistry and natural sciences at Williston Seminary, a post he held for 6 years, until he left for Germany to work for his doctor's degree.

In 1888, Dr. Cobb received the Ph.D. degree at the University of Jena, having had as teachers such famous men as Haeckel, Oscar Hertwig, Stahl, Kükenthal, and Lang. An appointment to the British table at the Zoological Station in Naples speaks for the young American's success and recognition. His doctor's thesis dealt with nematodes, or nemas as he later preferred to call them. Scientists at that time limited their study of this group of worms to those found parasitic in man and the higher animals. Dr. Cobb soon apprehended the significance of the free-living members as found in soil, in fresh, and especially in marine waters. He quickly sensed the opportunity which this field of research offered, but nematology at that time was not yet a profession and, although Dr. Cobb had to turn to other work to make a living, he seized every opportunity to make nematode collections and to study these organisms.

Dr. Cobb was connected with the New South Wales Department of Agriculture from 1891 to 1904, and during this period spent 3 years in the United States and Europe as an Agricultural Commissioner of New South Wales. It was in Australia that Dr. Cobb became associated with W. E. Chambers, who remained in this companionship until his death in 1918 and who is the author of most of the beautiful drawings that adorn Dr. Cobb's publications of this period.

From 1905 to 1907, Dr. Cobb was director of the Division of Physiology and Pathology of the Hawaiian Sugar Planters' Experiment Station. Various diseases of sugar cane were then the subject of his studies.

When in 1907 he joined the staff of the U. S. Dept of Agriculture in Washington, D. C., as Agricultural Technologist, another new field of research was to be his subject, namely, cotton and its standardization. He took a very active part in the building up of the fundamentals of this branch of agricultural economics, introducing many novel procedures. For some time also he was Assistant Chief of the Bureau of Plant Industry. Meanwhile the need for more extended investigations in the problem of plant-infesting nematodes and related free-living forms from the soil, fresh, and salt water arose, and Dr. Cobb was considered the best authority to do this work. Further developments showed that some nematode parasites of insects and other invertebrates were of importance as controlling factors of various obnoxious insect pests; the scope of the work was therefore extended to include such problems.

Undoubtedly Dr. Cobb's outstanding scientific accomplishments are in nematology. His faculty for keen observation, his knowledge of the microscope, and his skill in using it were the necessary requisites for success here.

Dr. Cobb was a member of numerous scientific societies; he was a past president of the Helminthological Society of Washington, of the American Microscopical Society, of the American Society of Parasitologists, and of the Washington Academy of Sciences. To his associates he set an example by his untiring optimism and ever-young enthusiasm. We miss the scientist that was Dr. Cobb, the colleague, the friend; but ours is a kind memory.—G. Steiner.

K. K. Gedroiz

1872–1932

On October 5, 1932, in Moscow, U. S. S. R., died Professor K. K. Gedroiz, member of the Russian Academy of Sciences and President of the Second Congress of the International Society of Soil Science.

Professor Gedroiz's contributions to our knowledge of the base exchange capacity and the colloidal properties of the soil have completely changed our ideas concerning this important branch of soil science. With the appearance in

this country of the mimeographed English translation of Professor Gedroiz's work in 1923, under the auspices of the U. S. Dept. of Agriculture, there was given a decided stimulus to the study of the physical-chemical properties of the soil, especially bearing on base exchange problems and on the reclamation of alkali soils. The name of Professor Gedroiz will stand as a representative of that famous group of soil scientists that Russia has given to the world, including Dokutschaiev, Sibirtzev, Kossowitch, Kostytchev, and Glinka.

Born in the southern part of Russia and educated at the Forestry Institute in St. Petersburg under the guidance of the prominent soil scientist, P. L. Kossowitch, Gedroiz became immediately interested in soil chemical investigations. His first problem dealt with the influence of various solvents in rendering phosphoric acid or low-grade phosphates available. His important investigations on the soil colloidal complexes and the absorbing capacity of the soil began to appear in 1908 and continued uninterruptedly until his death. Nearly 100 papers were written by him, dealing directly or indirectly with this subject. His ideas concerning the importance of the soil absorbing complex in soil processes and plant nutrition were incorporated in a monograph, the third edition of which has just appeared. This has also been translated into German.

Professor Gedroiz was also the author of a book entitled *The Chemical Analysis of Soils* which has gone through three editions in Russian and has been translated into German. Since 1915, he was the Editor of the Russian journal *Zhurnal Opitnoi Agronomii* (Journal of Experimental Agronomy). This journal has lately been suspended and has been incorporated with a new journal, *The Chemization of Socialistic Agriculture*, of which Professor Gedroiz was an editor.

Professor Gedroiz is survived by a wife and two children, both of whom have suffered severely as a result of the war and of the Revolution.—SELMAN A. WAKSMAN.

WILLIAM PARKER HEADDEN

1850 1932

William Parker Headden was born at Red Bank, New Jersey, September 21, 1850. He obtained his A.B. from Dickinson College in 1872 and his A.M. in 1873. His Ph.D. was obtained from Giessen in 1874. He was given the honorary degree of D.Sc. in 1919 by the University of Colorado. He was an assistant in the chemistry laboratory at Pennsylvania from 1874-76; Professor of Chemistry at Maryland from 1880-84; was in Denver University from 1884-89; in the South Dakota School of Mines as Professor of Chemistry, 1889-91 and as Dean from 1892-93; and he was Professor of Chemistry at the Colorado Agricultural College from 1893 until his death, February 5, 1932.

Dr. Headden was widely known in the West for his work with the rare earths, on radiation, on mineral waters, and on calcites. At Colorado, he worked out the value of saltbush as a feed. He did considerable work on alfalfa but his major agricultural discovery was the formation of nitrates in Colorado alkaline soils. Dr. Walter G. Sackett, working with Dr. Headden, proved that this excessive formation in nitrates was due to biological processes. Dr. Headden, however, worked out the chemical side of this problem. He showed that on our alkaline soils nitrates often rose to concentrations which would injure the quality of crops and sometimes prevent their growth. He did a great deal of work on the action and rôle of carbohydrates in the soil and showed the influence of different crops on the amounts of carbon dioxide to be found in the soil. A cycle of carbon dioxide production was found to correspond with the growth of the crop. When

the growth was active, carbon dioxide was very abundant; when the growth was low, carbon dioxide was low.

Dr. Headden felt that this carbon dioxide production in soils had a very marked effect upon the well being of soils. He did not live to work out all of the ultimate by ways that arose in this problem.

As it touches agronomy, Dr. Headden's most important work was concerned with alfalfa and his nitrate and carbon dioxide work in soils. He was a hard worker and a prolific producer in many fields of endeavor. At one time, he was looked upon in foreign countries as one of the four or five leading authorities on the rare earths.—ALVIN KEZER.

GEORGE JANSSEN

1897–1932

Dr. George Janssen died January 31, 1932, after a short period of sickness. Dr. Janssen was born in Wellsburg, Iowa, on June 28, 1897. He was graduated from the South Dakota College of Agriculture in 1921 and received his M.S. degree from the same institution in 1922. He served as assistant in agronomy at the Wisconsin Agricultural Experiment Station from 1923 to 1925, and received his Ph.D. degree from the University of Wisconsin in 1925.

Dr. Janssen was appointed assistant professor of agronomy and assistant agronomist at the Arkansas University and Experiment Station in 1926 and served in that capacity until his death.

Although comparatively young, his work on winterhardiness of small grains and on carbohydrate relationship in plants marked him as an able investigator from whom many more valuable contributions would have been given to science. —R. P. BARTHOLOMEW.

T. C. JOHNSON

1870–1932

Prof. T. C. Johnson, Director of the Virginia Truck Experiment Station at Norfolk, Va., and well known in the field of agronomical as well as horticultural research, died at Norfolk, Va., March 31, 1932. He was born at Long Reach, West Virginia, January 1, 1870, and obtained his early agricultural training on a West Virginia farm. He was graduated from the University of West Virginia in 1896 and received the degree of master of science from the same institution in 1900. He served as active professor of horticulture at the University of Missouri in 1901–02 and resumed his post-graduate studies as a fellow in horticulture at Cornell University in 1902–03. From 1903 to 1906 he was instructor in horticulture and botany and in 1906–07 assistant professor at the University of West Virginia. From 1908 to the date of his death he was Director of the Virginia Truck Experiment Station.

During the early years of his directorate, when the staff of research workers was relatively small, much of his time was spent in active research in agronomy and horticulture. Professor Johnson displayed a keen interest in agronomic affairs throughout his career, as was evidenced by the numerous papers presented before the members of this Society and by his regular attendance at its annual meetings.

He was particularly interested in research problems relating to the improvement and maintenance of fertility of the lighter types of soil of the Atlantic Coastal Plains area by the use of green manure crops, lime, and commercial fertilizers. The results of his studies regarding the nutrition of vegetable crops

and the use of different combinations of commercial fertilizers attracted the attention of fertilizer manufacturers and growers of vegetable crops over a wide area along the Atlantic Seaboard.

His outstanding ability as an executive and a director of research can be best measured by the growth of the Virginia Truck Experiment Station in personnel, equipment, and accomplishments during the 24-year period of his directorate. This institution with its well-equipped buildings and laboratories, its extensive area of land for field plat investigations, and its staff of research workers in horticulture, plant pathology, entomology, plant physiology, and soil technology stands as a monument to his broad vision, energy, and efficient management. His efforts in directing the course of research into channels pertinent to the needs of the trucking industry have resulted in accomplishments of great practical value and fundamental significance.

A wide circle of friends in many walks of life in Virginia and elsewhere have keenly felt the loss of one who showed so broad and active an interest in the civic as well as the agricultural affairs of his community, his state, and his country. —H. H. Zimmerley.

James Oscar Morgan

1880–1932

Dr. James Oscar Morgan, Professor of Agronomy and Vice-Dean of the School of Agriculture, Agricultural and Mechanical College of Texas, died at his home on the College Campus October 8, 1932. He was born at Etowah, North Carolina, in 1880. He received his B.S. degree at the North Carolina A. & M. College in 1905, the M.S.A. degree from Cornell in 1908, and the Ph.D. in 1909. He was professor of agronomy in the Mississippi A. & M. College from 1909 to 1912. During the latter year he was appointed professor of agronomy in the A. & M. College of Texas, a position he held until his death.

Dr. Morgan had a keen and abiding interest in agronomy and took an active part in the affairs of the Society. In 1924 he was a member of the Committee on Crops Teaching Methods and was Chairman of the Committee from 1925 to 1929. He was a member of the Committee on Education in Agronomy in 1930 and 1931. He was author of *Field Crops for the Cotton Belt* which is widely used as a text-book in the agricultural colleges of the southern states.

Dr. Morgan's scholarly attitude and high professional ideals were felt throughout the institution. In addition to his duties as head of the Department of Agronomy and Vice-Dean of the School of Agriculture, he was Acting Dean of the Graduate School in 1931–32.—A. B. Conner.

Harry William Warner

1894–1932

Harry W. Warner died on June 12, 1932, at Wilmington, Delaware, where he was visiting at the time. He was 38 years of age, having been born at De Smet, South Dakota, May 16, 1894.

Warner was graduated from the South Dakota State College at Brookings in 1916 and did graduate work at Iowa State College, receiving his master's degree in 1917. He served in the Air Service, U. S. Army, 1917–19, and at the close of the war returned to Ames as assistant in the soil survey. He was soon transferred to the extension service where he did very effective work as extension specialist in soils for six years.

In 1925, Warner joined the staff of The National Fertilizer Association as agronomist and remained in this work for the next five years. During that brief period he became widely known among the agronomists and agricultural workers of the country through his ability to popularize agronomic information, his clever humor, and his inimitable personality which endeared him to all who knew him.

Warner was an active worker in a number of community and fraternal organizations and had far more than one man's share of friends throughout the country. He was married in 1920 and is survived by his wife, Nellie Rowe Warner, and two sons, Keith and John.—H. R. SMALLEY.

THE ECONOMIC SITUATION

In addition to the usual work of the Committee we this year had from the President of the Society a special assignment, *viz.*, the investigation of the effect of the nation- and world-wide depression on agronomic work in the United States. The matter came to issue first on the basis of a report received from North Carolina concerning a very serious cut in funds available for the work of the North Carolina Agricultural Experiment Station. The question raised was whether the American Society of Agronomy could in any way assist the Director of the North Carolina Experiment Station through emphasizing the significance and importance of work which would have to be curtailed or eliminated altogether, on account of reduction in resources. Your Committee formulated the following resolution, and submitted the same to the North Carolina State Budget Commission:

"Through the newspapers, and on our initiative through correspondence with the director, R. Y. Winters of the North Carolina Experiment Station, we have been informed of the difficult financial situation in your State and of the proposal to discontinue certain appropriations for the support of the Agricultural Experiment Station. As the officially appointed Committee on Resolutions of the American Society of Agronomy, we are presenting below what we believe to be certain principles relative to the value of the agronomic research conducted by the Experiment Station, and of the almost irreparable loss should much of this work be arbitrarily discontinued. We are aware that only by your courtesy can the American Society of Agronomy have the privilege of being heard. We do not for a moment urge that priority be given to the agronomic research of the Experiment Station over other research conducted by the Station. We make our plea in full knowledge of the terribly difficult problems which you have before you in the necessity of adjusting state expenditures to the income which it is possible to secure. We feel, however, that it is not out of place for us to bring the above to your attention.

"In view of the present distressing situation in the cotton market and uncertainties as to the future, we regard the studies of crop rotation and crop sequence now being conducted by the Experiment Station as vital. They prepare the way for land management changes which may be inevitable, and it is easily conceivable that the final loss to the State, should the work be discontinued, and indeed to the Nation, may be far greater than the cost of your continued support of the research. We also believe that the work of the Experiment Station on the fertilizer requirement of North Carolina crops and of the conditions governing the most economical and proper use of fertilizer is fundamental in a State which spends more for fertilizer than any other state in the country. Studies on soils as now being conducted seem to be to us essential to the continued development of what is probably the greatest single resource of your State.

"In presenting the above we have chosen to speak in terms of work covered by the American Society of Agronomy, the only phase of the research work of the Experiment Station on which we can presume to speak with any degree of knowledge. It is because we feel so keenly the harm which may come from taking this step, that we trust you will accept our statement in the spirit in which it is intended."

When it later became apparent that the North Carolina situation was likely to be typical rather than exceptional, it seemed desirable to obtain a picture of the facts in the country at large. Certain territories were, therefore, assigned to individual members of the Committee on Resolutions, with a request for investigation and report. Unfortunately, through the withdrawal of Dr. Kelley from the Committee, it has not been possible to secure the facts for the far western territory. For the remaining territories we summarize briefly as follows:

1. In the group of states from Texas north through the Dakotas to the Canadian border, and east to the Mississippi River, but including Illinois and Wisconsin, there has been an average reduction of maintenance funds available for agronomic work of about 25%. Reduction in salaries of agronomic workers has averaged under 8%. Relatively few regular positions have been lost, although in 6 of the 13 states opportunity for graduate students is greatly decreased. Speaking in general terms, extension work has suffered somewhat less than either resident teaching or research. There is no indication that agronomic work has been any more adversely affected than work of other departments of the institutions concerned. Rather unanimously, our correspondents express a feeling of apprehension as to what may happen at the next legislative sessions having to do with budgets. There is fear, and doubtless ground for fear, that with "economy" becoming a political slogan, many crimes of an economic nature may be committed in its name.

2. In the second great group of states lying easterly from this first, and northerly of the Ohio and Potomac Rivers, the average decrease in budget is considerably less than in this first group. The states of Indiana, Michigan, Pennsylvania, and New Jersey, however, are meeting serious difficulty. Four states only, report no reduction in budget. Most of the reductions made have been absorbed in operating budgets, so that with the exception of two states personnel has not yet been reduced. Uncertainty as to the future is admitted. There is no evidence of agronomy having borne more than its fair share of the burden in institutional readjustments necessitated by curtailed budgets.

3. In the territory east of the Mississippi River and south of the Ohio and Potomac Rivers difficulties are general, but vary greatly in seriousness in the different states. Kentucky, Mississippi, and North Carolina find themselves embarrassed. In Kentucky, the agronomy budget has been cut 20%; in Mississippi the total funds for the whole station have for the biennial term been reduced from $250,000 to $90,000; and in North Carolina there has not only been a cut in direct appropriations, but receipts from sales of fertilizer tax tags have fallen off 47%. In these three states there have been salary cuts, in at least one a serious loss of personnel, and in all rearrangement of projects and inability even to consider the taking on of new work. In North Carolina for instance one-third of the agronomic projects have been discontinued.

The difficulty, however, is not confined to these three states. In Florida there has been a relatively small reduction in state appropriation, and a cut in salaries, but no loss of positions. In Virginia there has been a cut of about 10% in appropriations, which cut has in part been passed along to the staff members, but without as yet a loss in personnel.

It should be stated in passing that the report for the Southeast has more to do with research activities than it does with agronomic resident teaching and extension work. Because of varying types of organization in different states it has been difficult to secure a complete picture of all phases of agronomy. As far as your Committee has gone, however, there is no indication at all that agrono-

mic work has been more adversely affected in the South than other lines of Land-Grant institutional work, save as the work of agronomic research has been more often supported by receipts from sales of fertilizer tax tags, seed inspection fees, etc., than have other lines of work.

A fact of more than passing significance brought out by the survey of your Committee is that in those states which depend in large part on sales of products, and on receipts from miscellaneous inspection fees, there has been more difficulty than in states having a different basis of support. Since the nature of agronomic research is such as to require fairly consistent support year after year, it is suggested that when the time for organizing for the future comes consideration be given to a sounder and more permanent basis.

Another important fact is that horizontal cuts have to date been depended upon quite largely in meeting the financial situation. Your Committee is of the opinion that this must be considered as a temporary expedient only, necessary probably from the standpoint of protecting the workers from irreparable harm, but an unsound basis should the depression be long continued.

Your Committee has not formulated a resolution for presentation to the Society. Since the American Society of Agronomy is primarily a technical rather than an administrative organization, such a resolution would probably be considered as out of order. It suggests, however, that in case of rearrangements based on reduced appropriations the possibility of greater cooperation between states, with certain pieces of work developed on the basis of soil classification rather than of the arbitrary limits of state boundaries, be considered. This may even make possible the conduct of certain work at lower cost than in the past, and with a higher degree of efficiency.

Soil Erosion

The following resolution, being of a technical nature, was referred to the Soils Section without recommendation. Following discussion and approval by that group, it was incorporated in the report of this committee. The resolution is as follows:

Whereas, Losses of valuable soil by excessive erosion are steadily impoverishing and even destroying vast areas of crop and grazing land throughout the nation, and

Whereas, surveys have shown that not less than 75% of the agricultural lands of the nation are subject in some degree to such action,

Therefore be it Resolved, That the American Society of Agronomy go on record as affirming steadfast support to those agencies endeavoring to find more effective means for reducing this continuing waste of the farmers' capital and the nation's most indispensible asset, accomplishment of which constitutes a vitally important requisite of any sound plan of better land utilization, a step the nation can not afford not to take,

Be it Further Resolved, That this Society shall in every possible effective way lend support to the furtherance of:

1. The program recently inaugurated by the United States Department of Agriculture and the States, cooperating, directed toward the working out, experimentally, of the basic factors involved in erosional processes and the testing of every promising practical method for controlling this costly evil as it relates to various soil, climatic and vegetative conditions and to various types of land usage, recognizing that without these fundamental data it will not be possible to proceed in a scientific and expeditious manner toward the development of efficient, practical control measures, such as have long been needed and such as will be more and more needed;

2. The educational campaign designed to bring this menancing situation out into full light before the farmers, ranchmen, educators, economists and business men of the nation;

3. The carrying to the farmers and ranchmen of the country through the extension and other agencies the results of improved methods of erosion control worked out through the research program at the erosion stations that have been established in ten major soil and climatic regions,

Be it Further Resolved, That this resolution be published in the JOURNAL of the Society and that copies be put in the hands of those organizations and leaders interested in bringing about better practices and policies of land utilization.

Respectfully submitted,
F. D. KEIM
J. D. LUCKETT, *ex-officio*
S. B. HASKELL, *Chairman*.

OFFICERS' REPORTS

REPORT OF THE EDITOR

J. D. Luckett, Editor, presented the following report which, upon motion, was adopted:

The Editor of the JOURNAL of the American Society of Agronomy is not to be numbered among the forgotten men of 1932, if our correspondence and editorial output for the year are acceptable tokens of remembrance.

To present the year's activities as briefly as possible, let me give you a summary of the 1932 volume of the JOURNAL. Practically duplicating the 1931 volume in size, volume 24, the current volume of the JOURNAL, will contain 99 papers, 13 notes, and 18 book reviews, or 130 contributions in all in addition to numerous announcements, accounts of regional meetings, and other items of general agronomic interest. Forty-one papers are on hand awaiting publication, while 25 papers were returned during the year for various reasons, thus making a total of 196 contributions of one kind or another passing thru the Editor's hands thus far in 1932. With the appearance of the December number, we shall have published all papers received prior to May 1.

At this time last year, we had on hand 47 accepted papers as compared with 41 this year. However, this difference is too slight to raise hopes that publication in the JOURNAL can be speeded up during 1933, for the resources of the JOURNAL are not likely to show any marked upward trend in the immediate future and most certainly will not permit any increase in the size of the 1933 volume.

An examination of the program for this meeting is rather appalling from the point of view of the Editor. There are 62 papers listed on the program in addition to the three valuable and interesting contributions to agronomic literature that were presented at this afternoon's session. The program last year listed 44 papers. It may be of interest to many of you to know that so far as available material is concerned the JOURNAL is not in the least dependent for its existence upon papers presented at the annual meeting. We expect to give the usual consideration to any of these papers that you may wish to submit to the JOURNAL, but apparently the day is past for good when the Editor of the JOURNAL OF AGRONOMY will look to the annual meetings of the Society to replenish his stock of manuscripts.

The theme of several of our previous reports has been the necessity for more condensed papers in the JOURNAL, and we are not going to enlarge upon that topic at this time beyond expressing our appreciation of your response to our request for cooperation in this direction.

More than at any previous time in our editorship, we have resorted during the past year to outside reviewing of papers submitted to the JOURNAL. Exercising our editorial prerogatives we have called upon various members of the Society to review contributions on subjects in which we believed them to be especially well qualified to pass judgment. To these reviewers must go most of the credit for any improvement in the general tone and quality to be noted in the contents of the current volume. It is our pleasure to acknowledge the very considerable service that these men have rendered to the Society and to the JOURNAL.

Perhaps in this connection a brief word as to some of the things that make papers acceptable or unacceptable for publication in the JOURNAL might be of passing interest. Assuming that a paper is scientifically sound the most common obstacle met with from the editorial point of view is a persistent tendency to review all of the available literature on the subject. We have reached the age where we can say that this is peculiarly characteristic of the younger generation, but there are many agronomists of mature years who should know better. Almost invariably, lengthy reviews of the literature can be dispensed with and the value of the paper enhanced thereby.

Probably the next most common defect is a too detailed discussion of the problem and of the methods of attack and a tendency to present the data in unnecessary detail. Here, obviously, a well-informed reviewer is of tremendous help to the Editor.

A third defect often encountered is in the tabular presentation of data. This is especially important because tabular matter is the most expensive single item in the publication of the JOURNAL. Frequently, by a recombination of the material, the amount of tabulation required can be substantially reduced.

From these brief comments it will be apparent, I hope, that we are striving to present in the JOURNAL concise records of the discovery of new facts in the many fields of science which contribute to that subject that we call agronomy, leaving to other mediums the publication of more ambitious dissertations of a philosophical or abstract character that are unquestionably valuable additions to the literature of crop and soil science but that are beyond the resources of our publication.

After all, each paper presents its own problems and the splendid spirit of helpfulness invariably displayed by contributors to the JOURNAL when called upon to revise their contributions is one of the intangible rewards of the Editor's office.

As in other years, we are greatly indebted to the several representatives at the colleges and experiment stations over the country who supply us with news items and the material in the JOURNAL which is found under the heading of "Agronomic Affairs." Also, the close cooperation of the Secretary's office in maintaining the mailing list of the JOURNAL and in many other details has been indispensable to the efficient handling of the Society's publication.

Early in the year we assumed responsibility for accumulating and forwarding to *Biological Abstracts* each month author abstracts of the papers appearing in the current volume, as those of you who have published in the JOURNAL during the past few months are aware. This would seem to be well worth the little time and effort required, not only from the standpoint of *Biological Abstracts*, but from that of the author and the JOURNAL as well.

We have also continued work on the cumulative index of the JOURNAL which will supplement the index for the first 20 volumes published in 1928. In due time the Executive Committee will be asked to consider the publication of this index, covering volumes 21 to 25, inclusive, at the end of 1933.

Finally, we would leave with you the impression of the JOURNAL as a stabilized and self-contained enterprise; well prepared, with your continued support, to hold its own in 1933; and ready, when resources and circumstances permit, to expand its field of usefulness to the members of this Society.

Respectfully submitted,
J. D. LUCKETT, *Editor.*

REPORT OF THE TREASURER

The treasurer submitted his annual report as follows which was received and referred to the Auditing Committee.

I submit herewith the report of the Treasurer for the year November 1, 1931, to November 1, 1932:

Balance, last report, general fund		$496.34
Balance, last report, Lime Association fund		147.20
Total balance, last report		$643.54
RECEIPTS, 1932		
Dues, 1932	$4,116.50	
Dues, 1932 (new)	369.50	
Dues, 1931	10.00	
Dues, 1933	25.00	
Subscriptions, 1932	1,770.98	
Subscriptions, 1932 (new)	408.00	
Subscriptions, 1931	54.30	
Advertising income	695.38	
Reprints sold	747.26	
Journals sold	199.44	
Total income, 1932	$8,396.36	$8,396.36
Total income plus balance		$9,039.90
DISBURSEMENTS, 1932		
Printing JOURNAL, reprints, engraving, etc. (12 issues)	$7,003.72	
Salary, business manager	745.00	
Postage (secretary and business manager)	173.63	
Printing (miscellaneous, programs, etc)	168.25	
Express on JOURNALS	37.49	
Mailing clerk	60.25	
Refunds, checks returned, collection charges, and tax	121.83	
Miscellaneous expenses (badges, supplies, expenses annual meeting, etc.)	270.17	
Total disbursements, 1932	$8,580.34	$8,580.34
Balance on hand		$ 459.56

Total receipts	$9,039.90	
Total disbursed	8,580.34	
Balance	$ 459.56	
Balance in Lime Association fund		$ 147.20
Balance in general fund		312.36
Total		$ 459.56

Respectfully submitted,
F. B. SMITH, *Secretary-Treasurer.*

Approved by the Auditing Committee.

F. D. KEIM
H. G. M. JACOBSON, *Chairman.*

REPORT OF THE ASSISTANT TREASURER

A. G. McCall presented the report of the Assistant Treasurer which upon motion was referred to the Auditing Committee.

Receipts

Sale of Proceedings of First International Congress of Soil Science (Washington, 1927)	$ 123.00	
Membership dues and initiation fees for International Society of Soil Science	842.80	
Interest on savings account with Prince Georges Bank and Trust Co., Hyattsville, Md	68.11	
	$1,033.91	
Balance on hand in bank Nov. 6, 1931 (Savings)	1,948.73	
Balance on hand in bank Nov. 6, 1931 (Checking)	134.41	
		$3,117.05

Expenditures

Membership dues and initiation fees for International Society of Soil Science, transmitted to Dr. Hissink, General Secretary, of the Society	$ 842.80	
Postage for office correspondence	16.00	
Rumford Press (including labor, postage, etc., for distribution of Proceedings)	34.74	
Premium on bond for Dr. A. G. McCall, treasurer	5.00	
	$ 898.54	
Tax of 2 cents each on checks (Bank charge)	.12	
	$ 898.66	
Balance on hand Nov. 10, 1932 (Savings)	$2,016.84	
Balance on hand Nov. 10, 1932 (Checking)	201.55	
		$3,117.05

Respectfully submitted,
A. G. McCall, *Exec. Sec.*,
American Organizing Committee.

Found correct by the Auditing Committee.

F. D. Keim
H. G. M. Jacobson, *Chairman.*

REPORT OF THE SECRETARY

The report of the Secretary was presented and upon motion was adopted as follows:

Membership

The membership of the Society has decreased slightly during the year, but this decrease has been kept as small as possible. Many letters have been sent out urging members to remain in the Society. State representatives have been active in getting new members, but not as many new members have been secured as in former years. This is easily understood when one considers that present economic conditions are unprecedented in the history of the Society. The aid given by state representatives in this connection in the face of such conditions is greatly appreciated. We shall certainly need more help during the coming year to prevent a larger decrease in membership and your loyal support is strongly urged at this time.

The membership of the Society at the last report was 963. The total increase for the year was 89 and the total decrease 103, giving a net decrease of 14 members for the year. The membership on November 1, 1932, was 949.

Memberships and Subscriptions by States and Countries

	Members	Subscriptions
Alabama	8	2
Arizona	12	1
Arkansas	5	4
California	32	11
Colorado	17	2
Connecticut	11	3
Delaware	5	2
District of Columbia	71	5
Florida	16	3
Georgia	14	3
Idaho	6	2
Illinois	36	16
Indiana	23	2
Iowa	35	5
Kansas	33	2
Kentucky	10	3
Louisiana	13	3
Maine	5	1
Maryland	15	2
Massachusetts	14	7
Michigan	23	5
Minnesota	22	4
Mississippi	6	3
Missouri	22	4
Montana	21	2
Nebraska	21	3
Nevada	1	2
New Hampshire	1	1
New Jersey	17	3
New Mexico	4	1
New York	44	19
North Carolina	16	2
North Dakota	15	1
Ohio	38	6
Oklahoma	19	4
Oregon	18	3
Pennsylvania	17	5
Rhode Island	6	1
South Carolina	10	1
South Dakota	10	1
Tennessee	10	4
Texas	35	7
Utah	13	6
Vermont	2	1
Virginia	20	1
Washington	10	4
West Virginia	9	1
Wisconsin	29	4
Wyoming	3	2
Alaska	0	1
Canada	27	37
Cuba	2	1
Hawaii	11	11
Philippine Islands	3	5
Porto Rico	1	3
Africa	7	32
Argentina	6	6
Australia	2	24
Brazil	3	1
British Guiana	0	1
British West Indies	1	1
Ceylon	0	3
China	9	26
Colombia	1	0
Czechoslovakia	0	1
Denmark	1	1
Dominican Republic	1	0
Dutch East Indies	0	2
Egypt	1	1
England	3	11
Estonia	0	1
Federated Malay States	0	2
Fiji	0	2
Finland	1	2
France	0	6
Germany	4	7
Greece	1	1
Haiti	0	1
Holland	0	3
Honduras	1	1
India	4	17
Ireland	0	3
Italy	1	5
Japan	4	65
Jugoslavia	1	2
Mauritius	0	1
Mesopotamia	1	1
Mexico	1	1
Morocco	0	1
Norway	1	1
North Wales	0	1
Peru	3	2
Poland	1	1
Portugal	0	2
Roumania	0	3
Scotland	0	5
South Wales	0	1
Spain	0	1
Sweden	2	4
Switzerland	1	0
Turkey	1	1
Uruguay	1	1
U. S. S. R	6	51
Wales	1	1
West Indies	0	1
	949	546

Membership Changes, 1931–32

Membership, last report			963
New members, 1932		75	
Reinstated members		14	
Total increase		89	
Dropped for non-payment of dues	93		
Resigned	6		
Died	4		
Total decrease	103	103	
Net decrease		14	14
Membership, Nov. 1, 1932			949

Members by Years

1908 (charter members)	29	1921	43
1908	8	1922	42
1909	5	1923	26
1910	13	1924	37
1911	21	1925	65
1912	12	1926	55
1913	15	1927	59
1914	12	1928	58
1915	19	1929	90
1916	32	1930	76
1917	13	1931	91
1918	11	1932	75
1919	14		
1920	27		949

Total Membership by Years

1908	121	1917	652	1925	646
1909	129	1918	509	1926	700
1910	176	1919	473	1927	767
1911	236	1920	436	1928	823
1912	295	1921	592	1929	906
1913	349	1922	643*	1930	943
1914	397	1923	561	1931	963
1915	471	1924	577	1932	949
1916	586				

*In 1922 the dues were increased to five dollars.

Subscriptions have also suffered a slight decrease this year. This decrease consists mostly in foreign subscriptions which were not renewed. This can also be understood because of conditions in some foreign countries. There were 565 subscriptions last year and 546 this year, a decrease of 19.

Subscriptions

Subscriptions, last report		565
Subscriptions dropped	110	
New subscriptions	91	
Net decrease	19	19
Subscriptions, Nov. 1, 1932		546

Finances

The report of the Treasurer shows the finances of the Society to be sound. Twelve issues of the Journal have been paid for and the Society has kept out of debt.

MEETINGS

Reports of the meetings of the Society during the year have been given in the JOURNAL and need not be given in detail here. The annual meeting of the Northeastern Section of the Society was held at Geneva and Ithaca, New York, in connection with the summer meeting of the American Association for the Advancement of Science. The summer meeting of the Corn Belt Section of the Society was held in connection with the American Society of Plant Physiologists at Madison, Wisconsin. The meeting of the Southern Section has been indefinitely postponed and a report on the meeting of the Western Section appears in this number of the JOURNAL. Student sections of the Society will be reported on by a special committee appointed by President Brown.

The winter meeting of the Society will be held at Atlantic City on December 28 with Section O (Agriculture) of the American Association for the Advancement of Science. A symposium on nitrogen has been arranged. Next summer, probably in June, a meeting will be held with the American Association for the Advancement of Science in Chicago in connection with the Exposition. Several distinguished foreign scientists will be in attendance and will participate in the program.

In conclusion, I would express my deep appreciation of the courtesy shown an inexperienced Secretary by all members and officers of the Society and I am especially grateful to President Brown for help with the work as Secretary throughout the year.

Respectfully submitted,
F. B. SMITH, *Secretary.*

FELLOWS

The Fellows-elect were announced by Vice-President R. I. Throckmorton (pages 987 to 989) and were presented with diplomas. Those receiving this honor were Dr. A. B. Beaumont, Professor Andrew Boss, Dean M. J. Funchess, Dr. S. C. Salmon, and Dr. F. T. Shutt.

THE NEW CONSTITUTION

The draft of the new constitution as prepared in accordance with the report of the Reorganization Committee submitted to the Society at the last annual meeting was read and acted upon article by article. The constitution as presented in the JOURNAL, Volume 24, pages 839–841, was adopted with the following minor modifications:

Article 4 should read "A Crops Section and a Soils Section."

Article 7, second sentence, was changed to read "The President and Vice-President shall be, etc."

The constitution, with these minor modifications, was then adopted as a whole.

The by-laws were acted upon article by article and with the following modifications were adopted as printed in the JOURNAL:

Number 3 of the by-laws was changed to read "One meeting of the Society shall be held *each* year."

Number 4 was changed to read "The annual meeting of the Society shall consist of one or more general sessions and sectional sessions in Crops and Soils."

Part 4 under Number 6, the second sentence, was changed to read "The sectional chairman shall be responsible for the organization of the programs for their respective sections."

Number 7 was eliminated and the following statement substituted: "Special committees may be appointed by the Executive Committee as deemed desirable." The by-laws as amended were then approved.

TWENTY-FIFTH ANNIVERSARY PROGRAM

At 2 p.m. on Thursday, November 17, the twenty-fifth anniversary program of the Society was given as follows, with President P. E. Brown presiding:

"History of the Organization of the American Society of Agronomy." T. L. Lyon, Historian, Cornell University.

"A Quarter Century of Development in Soil Sciences." J. G. Lipman, New Jersey Agricultural Experiment Station.

"A Quarter Century of Progress in the Development of Plant Sciences." C. W. Warburton, U. S. Dept. of Agriculture.

ANNUAL DINNER

At 6:30 p.m. on November 17 the annual dinner of the Society was held at the Willard Hotel, at which time Dr. P. E. Brown delivered the address of the retiring president (pages 935 to 950).

The report of the Nominating Committee, made up in accordance with the provision of the new constitution adopted by the Society, was presented by the chairman, President P. E. Brown, and the following officers of the Society were declared elected for 1933: M. A. McCall, Bureau of Plant Industry, Washington, D. C., *President;* R. I. Throckmorton, Kansas State College, Manhattan, Kansas, *Vice-President;* C. H. Myers, Ithaca, New York, and J. J. Skinner, Washington, D. C., Representatives of the Society on the Council of the A.A.A.S.

Meeting adjourned.

F. B. SMITH, *Secretary.*

ABSTRACTS OF PAPERS PRESENTED AT THE ANNUAL MEETING

Failure to dispose of a sufficient number of the abstracts of papers presented at the annual meeting to those who attended the sessions in Washington to defray at least part of the cost of printing renders it impractical under present financial conditions to publish the abstracts in this number of the JOURNAL, as was originally planned. Copies of the abstracts may be obtained from the Secretary of the Society at fifty cents each.

OFFICERS OF THE SOCIETY FOR 1932

M. A. McCall, Washington, D. C., *President*

R. I. Throckmorton, Manhattan Kans. *Vice-President*

Richard Bradfield, Columbus, O. *Chairman*, Soils Section

M. T. Jenkins, Ames, Iowa, *Chairman*, Crops Section

C. H. Myers, Ithaca, N. Y.; J. J. Skinner, Washington, D. C.
Representatives on the Council of the A. A. A. S.

P. E. Brown, Ames, Iowa *Secretary-Treasurer*

J. D. Luckett, Geneva, N. Y. *Editor*

AGRONOMIC AFFAIRS

RECOMMENDATIONS FOR 1933 WITH REFERENCE TO THE FERTILIZATION OF FLUE-CURED, SUN-CURED, AND SHIPPING TOBACCO GROWN ON AVERAGE SOILS IN VIRGINIA, NORTH CAROLINA, SOUTH CAROLINA, AND GEORGIA

I. FERTILIZERS FOR BRIGHT FLUE-CURED TOBACCO

1. Analyses of Mixtures:

(1) *For heavy or more productive soils.* -Eight per cent available phosphoric acid, 3% ammonia, and 5% potash.

(2) *For light or less productive soils.*—Eight per cent available phosphoric acid, 4% ammonia, and 6% potash.

2. For Control of "Sand-Drown" (Magnesia Hunger):

It is recommended that fertilizers carry 2% magnesia (MgO). This may be derived from any material carrying magnesia in forms known to be readily available to the plant, such as sulfate of potash-magnesia and magnesium sulfate.

3. Chlorine:

Available experimental data from bright tobacco sections of Virginia, North Carolina, South Carolina, and Georgia show that a small quantity of chlorine in the tobacco fertilizer increases the acre value of the crop. Experiments have shown, however, that an excessive amount of chlorine in fertilizers used for tobacco injures its growth and reduces quality, producing a thick brittle leaf, which when cured becomes thin, soggy, and dull in color. It also has an unfavorable effect upon the burning quality of the cured leaf. It is recommended, therefore, that fertilizers be compounded in such proportions that the fertilizer mixtures shall contain 2% chlorine.

Note 1: The above analyses may be modified, provided the given ratios are maintained and the recommended sources of plant food materials are used.

4. Amount of Fertilizer:

Use 800 to 1,200 pounds per acre in the drill, thoroughly mixed with the soil within 10 days prior to transplanting. If analyses are

modified as suggested in Note 1, use equivalent amounts of plant food materials per acre. Poor stand troubles from heavy applications of soluble plant food materials may be avoided and loss from leaching reduced by applying a part of the mixture as a side-dressing about 20 days after transplanting.

5. Source of Plant Food Constituents:

   (1) *Phosphoric acid.*—Derived from superphosphate.

   (2) *Potash.*—Derived from any source of available potash, provided the chlorine content of the mixed fertilizer so compounded does not exceed 2%. If tobacco by-products are used as a source of potash, these must be sterilized to guard against spread of disease.

   (3) *Ammonia.*—One-half of the ammonia should be derived from high grade organic materials of plant or animal origin, such as cottonseed meal, fish scrap, and high grade tankage. At least one-fourth of the total ammonia is to be supplied by nitrate of soda. The remainder should be derived from such materials as urea or standard inorganic sources of ammonia. For the heavy Cecil soils of Virginia three-fourths of the ammonia may be derived from the above-designated mineral sources and one-fourth from organic sources of plant or animal origin

   Urea, though classified as an organic material, is considered, for the purpose of these recommendations, as an inorganic material. Because when added to the soil in fertilizer mixtures its action is similar to that of inorganic fertilizer materials.

   Explanatory note: The above-mentioned materials are recommended for fertilizer mixtures because experiments have shown that when applied at the rates suggested they carry calcium, sulfur, magnesium, and chlorine in addition to nitrogen, phosphorus, and potassium, in proportions which seem to be adequate for the needs of the tobacco plant.

II. FERTILIZERS FOR DARK TOBACCO (SUN-CURED AND SHIPPING)

1. Analyses of Mixtures:

   Use 8% available phosphoric acid, 3% ammonia, and 3% potash.

   Note 2: The above analysis may be modified, provided the given ratios are maintained and the recommended sources of plant food materials are used.

2. Amount of Fertilizer:

   Use 600 to 1,000 pounds per acre in the drill thoroughly mixed with the soil within 10 days prior to transplanting. If analysis is modified as provided for in Note 2, use equivalent amounts of plant food materials per acre.

3. Source of Plant Food Constituents:
   (1) *Phosphoric acid.*—Derived from superphosphate.
   (2) *Potash.*—Derived from any source of available potash, provided the chlorine content of the mixed fertilizer so compounded does not exceed two per cent. If tobacco by-products are used as a source of potash, these must be sterilized to guard against spread of disease.
   (3) *Ammonia.*—One-half of the ammonia should be derived from high grade organic materials of plant or animal origin such as cotton seed meal, fish scrap, and high grade tankage. At least one-fourth of the total ammonia is to be supplied by nitrate of soda. The remainder should be derived from such materials as urea or standard inorganic sources of nitrogen.

III. FERTILIZERS FOR PLANT BEDS

Injury due to excess of chlorine has been widely observed in tobacco plant beds. Since fertilizers are applied to plant beds in relatively large quantities, even a small percentage of chlorine in the fertilizers may cause plant bed injury. It is recommended, therefore, that only such materials as are practically free of chlorides be used for making plant bed fertilizers. It is recommended, too, that a fertilizer containing 8% phosphoric acid, 5% ammonia, and 3% potash from the same sources as recommended under Section 1 Sub-section 5, except that all potash be derived from high grade, sulfate of potash or sulfate of potash magnesia, be used. The addition of 1% available magnesia (MgO) will be beneficial in certain cases and its inclusion is generally to be recommended.

IV. ADDITIONAL STATEMENTS IN REFERENCE TO CULTURAL PRACTICES

(1) *Lime.*—Although lime is not recommended for use on bright tobacco lands, in cases of acid soils where the pH falls below 5, applications of dolomitic limestone broadcast at the rate of 1,000 pounds to the acre once in 3 or 4 years is advised.
(2) *Soil type.*—For the Cecil soils of Virginia, which are not particularly well adapted to the production of bright tobacco, 3% potash in a 1,000-pound per acre application seems sufficient.

For some of the better types of bright tobacco soils where high topping is practiced, 8 to 10% potash in a 1,000-pound per acre application may often be used with profitable results, and where soils are known to be high in available nitrogen the ammonia in the applied fertilizer should be reduced from the amounts recommended in Section 1, paragraph 1.

Tobacco Committee of the U. S. Dept. of Agriculture and the states of Virginia, North and South Carolina, and Georgia, cooperating:

W. W. Garner	E. Y. Floyd
F. A. Wolfe	L. G. Willis
T. B. Hutcheson, *Secretary*	E. G. Moss
T. L. Copley	J. M. Carr
H. P. Cooper	E. C. Westbrook
W. B. Rogers	C. B. Williams, *Chairman*.
W. M. Lunn	

MEETING OF THE WESTERN BRANCH OF THE SOCIETY

The sixteenth annual meeting of the Western Branch of the Society was held at the University of Wyoming, Laramie, Wyo., on July 25 and 26 with 41 agronomists in attendance. The following papers were presented and discussed:

The Comparison of Methods for Estimating Available Phosphorus in Calcareous Soils and the Behavior of Superphosphates in Calcareous Soils, by R. D. Hockensmith, Robert Gardner, and James Gardner, Colorado Agricultural College.

Influence of Chemical Composition of Organic Matter on the Rate of Decomposition, by T. L. Martin, Brigham Young University.

Rate of Nitrification and Nitrogen Fixation in Soils of the Arkansas Valley, by Robert Gardner, Substation, Rocky Ford, Colo.

Relation Between Bushel Weight and Maturity of Corn, by W. H. Leonard, Colorado Agricultural Experiment Station.

Relation of Annual Precipitation on Crop Yields at North Platte, L. L. Zook, Substation, North Platte, Nebr.

Border Effects under Different Irrigation Treatments, by D. W. Robertson, Colorado Agricultural College.

Sex in Seed Plants, by E. W. Bressman, Oregon State College.

The Comparative Costs and Efficiency of Tillage and Chlorates in Weed Control, by D. C. Tingey, Utah Agricultural College.

Some Phases of Weed Control, by D. R. Sabin, Wyoming Agricultural College.

Methods of Handling Seed Registration in Colorado, T. G. Stewart and John Spencer, Colorado Agricultural College.

Potato Seed Certification in Wyoming, by Glen Hartman, Wyoming Agricultural College.

Some Hard Seed Problems in Arizona, by Ian A. Briggs, Arizona Agricultural College.

The Results of Range Control and Proper Land Utilization in Montana, with Special Reference to Supervised Grazing in the Mizhah-Pumpkin Creek Grazing Reserve, by Clyde McKee, Montana Agricultural College.

Factors Influencing Carrying Capacity and Improvement of Western Ranges, by A. F. Vass, Wyoming Agricultural College.

At the conclusion of the program officers for the year were elected as follows: D. E. Stevens of Oregon, *President;* T. C. Stewart of Colorado, *Vice-president;* and Ian A. Briggs of Arizona, *Secretary*. It was voted to hold the 1933 meeting at the University of Arizona.

OUT WHERE THE WEST BEGINS

(Western Colorado)

Out where the soils are a little drier,
Out where the pH is a little higher—
That's where the West begins.
Out where the sun shines a little brighter,
Where the alkali is a trifle whiter,
And the sodium clays are a wee bit tighter—
That's where the West begins.

Out where the farmers feel a trifle "bluer,"
Because fertile fields are becoming fewer—
That's where the West begins.
Out where the "'chico' spots" are showing,
Where there're soil colloids in every streamlet flowing,
Where there's less of reaping and more of sowing—
That's where the West begins.

Out where the "solonets" were spoiled in the making,
Where the "solonchaks" are free for the taking—
That's where the West begins.
Where the organic matter content needs supplying,
Where there're sodium ions that cause the sighing,
But could be replaced without half trying—
That's where the West begins.

C. H. Dodson, *Colorado Agricultural College, Fort Collins, Colo.*

NEWS ITEMS

Dr. John H. Parker of Kansas State College has been invited to give the Spragg Memorial Lecture at Michigan State College in January, 1933. These lectures are given under the auspices of a memorial to Professor F. A. Spragg who directed the plant breeding work at the Michigan Agricultural Experiment Station from 1906 until his death in 1924.

Dr. H. H. Love, who is on leave of absence from Cornell University while serving as Agricultural Adviser to the Chinese Government, has recently been in Shantung Province where he was called to advise relative to the agricultural program of the Province. Dr. Love has just completed a national program for the development of the agricultureof China and has presented this to the Minister of Industries.

T. S. Buie of the Superphosphate Institute in Washington, D. C., has issued a summary in mimeographed form of the use made in the United States of rapid methods for the determination of soil phosphorus, arranged by states. A copy of the summary may be obtained upon application to Mr. Buie.

The American Cyanamid Company is celebrating its twenty-fifth anniversary this year, as described in the current number of *American Hortigraphs and Agronomic Review*. The Company is maintaining nine agricultural fellowships in this country and one in Canada, representing a wide range of soil and climatic conditions and a large variety of crops.

A. W. YOUNG received the doctorate degree in soil bacteriology at Iowa State College in June. At the beginning of the school year he joined the staff of the Bacteriology Department at the University of Tennessee where he is teaching courses in general and agricultural bacteriology.

THE IOWA SECTION of the American Society of Agronomy held its annual fall mixer and reception to new members and graduate students on October 13. Dr. P. E. Brown gave the principal talk of the evening on the "Organization and Aims of the American Society of Agronomy." At the regular meeting of the Iowa Section on October 26, Dr. A. G. Black, head of the Agricultural Economics Department at Iowa State College, discussed "Recent Trends and Developments in Agriculture."

OLIVER E. OVERSETH, who received the doctor's degree in soils at Iowa State College in June and who was formerly in charge of the western office of the Synthetic Nitrogen Products Corporation, is now in Europe visiting and studying at certain universities and agricultural experiment stations. He expects to spend the major portion of his time this fall in England at Cambridge University and the Rothamsted Experiment Station. Later he intends to go to Germany where he will continue his studies.

ARTHUR H. POST, absent on sabbatical leave, has returned to active duty at Montana State College from a year's work at the University of Wisconsin. His time was spent in soils and related subjects.

WILLIAM B. NELSON, formerly a student assistant in agronomy at Montana State College, is now at the University of Nebraska pursuing graduate work in agronomy.

HORACE G. BOLSTER, a 1932 graduate in agronomy of Montana State College, is working towards a master's degree in marketing at the Iowa State College.

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